PI-MAX®4 System

Princeton
Instruments

Revision History

Issue	Date	List of Changes
4	September 11, 2014	Issue 4 of this document incorporates the following changes: • Added information about the 1024EM and 1024EM(B) cameras.
3	October 11, 2013	Issue 3 of this document incorporates the following changes: • Added Section 13.3.3.3, Custom, which details the use of custom RF gating in LightField for PI-MAX4: 1024i-RF systems; • Added PI-MAX4: 2048f information; • Updated Appendix A, Technical Specifications; • Added Section A.5, CCD Specifications.
2	July 24, 2013	Issue 2 of this document incorporates the following changes: • Added Chapter 14, PI-MAX4: EM Family, and other EM-supporting information throughout the document; • Updated the Declarations of Conformity.
1.B	February 11, 2013	Issue 1.B of this document incorporates the following changes: • Editorial, graphic, and global nomenclature updates.
1.A	February 27, 2012	This is the initial release of this document

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Warnings and Cautions

WARNING!

When biased ON, intensified CCD cameras, such as the PI-MAX$^®$4 can be irreparably damaged if continuously exposed to light levels higher than twice the A/D saturation level. Therefore, it is *critical* that conditions *not* be created which could result in damage to the intensifier. Although intensified cameras are less prone to damage from *background light* when operated in gated mode, they are at *significant risk* to damage from high-intensity light sources such as a laser. High-intensity sources can damage the intensifier before protection circuits have time to respond, or even cause spot damage without the protection circuits acting at all. If a sustained alarm indication occurs when the controller is turned on, either completely cover the intensifier to reduce the light to halt the overload condition, or further reduce the laboratory illumination until safe operating conditions have been established.

Alarm

To reduce the risk of camera damage, the PI-MAX4 camera is equipped with an audible alarm in the camera head, activated when the intensity of light falling on the image intensifier exceeds a preset threshold. While the alarm is sounding, the photocathode is disabled. Immediately switch the **I.I.T.** switch (on the back of the PI-MAX4) to the **OFF** position. Cover the camera window and only switch the **I.I.T.** switch to **ON** after the illumination level has been lowered. If the alarm sounds continuously even when the illumination level is adequately low, shut the system down and contact the factory for guidance.

NOTE:

It is normal for the alarm to sound briefly when the system is first turned on.

CAUTION!

Discontinue operation and contact the factory immediately if sporadic or continuous unwarranted alarms continue. They may be an indication of intensifier damage or another condition which may require immediate attention.

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Chapter 1:   Introduction

The Princeton Instruments PI-MAX$^{\circledR}$4 Intensified CCD camera is designed for general macro-imaging and microscopy imaging applications. It is ideal for applications involving ultra low light measurements, or measurements of transient effects. PI-MAX4 uses a proximity-focused micro-channel plate (MCP) image intensifier (Gen II and Filmless Gen III intensifiers available) fiber-optically coupled to a CCD array. The fastest intensifiers can be gated in as little as 3 ns or less (option board allows gating to <500 ns) with an exceptionally high on/off light-transmission ratio. The CCD array provides a low noise, high dynamic range readout device that can be scanned at a variety of pixel rates. A number of different arrays are available to match the PI-MAX4 to the widest possible range of experimental requirements. In operation, data acquired by the camera is routed to the computer for processing and display. The computer controls both the system configuration and data acquisition via software, of which Princeton Instruments LightField® and WinView/32 are examples.

Except where specifically noted, the information within this system manual pertains to the following camera systems:

- PI-MAX4: 512EM
- PI-MAX4: 512EM(B)
- PI-MAX4: 512EM
- PI-MAX4: 1024EM(B)
- PI-MAX4: 1024 x 256
- PI-MAX4: 1024i
- PI-MAX4: 1024i-RF[a]
- PI-MAX4: 1024f
- PI-MAX4: 2048F

    a.   May also be referred to as **PI-MAX4-RF** within this manual.

1.1   PI-MAX4 System Components

All PI-MAX4 systems consist of standard hardware and software as well as the appropriate interface hardware for your computer system. Figure 1-1 illustrates the set of typical system components included with all PI-MAX4 systems.

Figure 1-1:   Typical PI-MAX4 System Components

The following items are standard with all PI-MAX4 systems:

- **Camera**

  The PI-MAX4 camera houses the CCD and intensifier and it supplies all of the high voltages needed to operate the intensifier (refer to Chapter 3, System Setup, for more information.)

  Cooling within the camera is performed by a cooling fan and a multi-stage Peltier cooler that is thermally coupled to the CCD (liquid coolant circulation can also be used for the PI-MAX4 camera.) Photocathode cooling to reduce equivalent background illumination (EBI) can be achieved via a chilled dry nitrogen source. C-, F-, and Spectroscopy-mount adapters are supplied (one of which is factory-installed.)

  The camera can be operated in one of the following two modes:

  — Safe Mode

    In Safe mode, the photocathode is gated off.

  — Gate Mode.

    In Gate mode, the photocathode is biased on only during the time each gate pulse is applied.

  The PI-MAX4 contains the analog and digital electronics, scan control and exposure timing hardware, and controller I/O connectors. Readout modes supported include full resolution, simultaneous multiple sub-images, and non-uniform binning. Single or multiple software-defined regions of interest can also be tested without having to digitize all the pixels of the array. Flexible exposure, set through software, is also fully supported.

  The PI-MAX4 contains two High Speed analog-to-digital converters. The effective digitization rate is software-selectable. After the data is converted, it is transferred directly from the camera to the host computer memory via the high speed interface cable.

- **Cable**

  AUX I/O Cable: 6050-0660, female DB26 to 5 BNC.

- **Computer Interface**

  Standard Ethernet Cable: 6050-0621, 5 meter. Other lengths up to 100 m are available.

  User-provided GigE interface card. (Intel Pro1000 recommended)

- **Tubing**

  Clear PVC tubing, 3', 5/32" OD, 1/32" wall (McMaster-Carr 5006K42) for dry nitrogen cooling of photocathode.

- **Manuals**

  PI-MAX4 System manual and optional application software manual.

- **Optional Application Software**

  — Princeton Instruments' WinView/32 or WinSpec/32.

  — Princeton Instruments' LightField.

1.2 Summary of PI-MAX4 Data Acquisition

Figure 1-2 illustrates the major components that comprise an Intensifier-CCD.

Figure 1-2: Major Components of the Intensifier-CCD
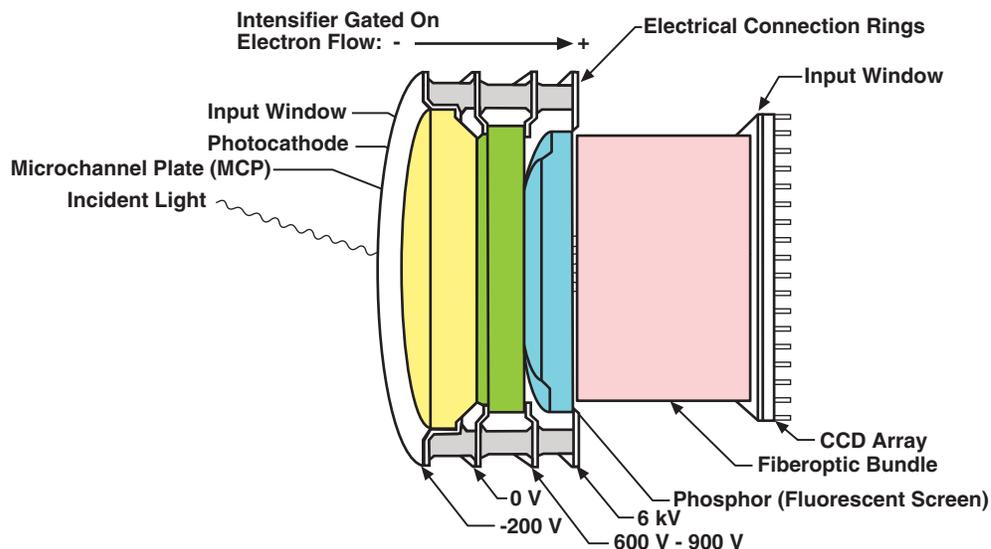
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In the PI-MAX4 camera, the input image is focused onto the photocathode of an image intensifier tube. The tube electronically amplifies the image and outputs it, much brighter, as gray-scaled green light. That light is then coupled to the CCD using a fused fiber-optic bundle from the output of the image intensifier to the front side of the CCD. The image at the output of the image intensifier is translated to the input of the CCD at the same size.[1] After being detected by the CCD, the image is read out to the internal controller, where it is digitized, and then transferred to the computer for processing via a high-speed data link.

The sequence below steps through the process by which photons are converted to data that can be displayed on a computer monitor. For the sake of simplicity, triggers and gate pulses are not mentioned and it is assumed that a high speed (GigE) serial interface card is installed in the host computer. When reading through the sequence, keep in mind that electrons are attracted to more positively charged surfaces and are repelled by more negatively charged surfaces. This principal is used to control electron flow through the intensifier tube: changing the photocathode voltage with respect to the voltage at the MCP input is used to switch (gate) the intensifier on and off.

1. Incident photons pass through the intensifier input window, strike the photocathode, and release electrons. See Figure 1-2.

2. Assuming that the intensifier is gated ON (the photocathode is more negative than the MCP input,) these electrons will be attracted to the MCP input. **Gating acts like a shutter in that gating the intensifier on allows the CCD to see light and gating the intensifier off prevents the CCD from seeing light.**

3. Since the voltage at the MCP output is much more positive, most of the electrons accelerate into the MCP channels and, if they hit the channel walls, will generate additional electrons, resulting in electron gain. **The amount of gain is adjusted by increasing or decreasing the voltage at the MCP output.**

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1. Units having a tapered fiber optic bundle may also be available. Contact the factory for information.

4. When the electrons exit the channels they are further accelerated by a constant high voltage (5-6 kV) and strike the phosphor coating on the fluorescent screen causing it to release photons. **Because of the MCP gain, there are now many photons for each photon that struck the photocathode surface.**

5. The photons released by the coating are transferred to the surface of the CCD (via fiber-optic) and produce charge at the pixels they strike. Note that fiber-optic coupling is not only the most efficient coupling possible, but lens-coupling effects such as vignetting are eliminated.

6. Charge accumulates in the pixel wells until the intensifier is gated off (the photocathode is more positive than the MCP input) and the phosphor decays.

7. At that point, the accumulated charge is shifted to the serial register where it is read out to an on-chip amplifier that converts the charge to an analog voltage.

8. This voltage is input to the selected analog-to-digital (A/D) converter(s) where it is digitally encoded. The conversion speed and the quality of the data are dependent on the effective ADC rate.

9. The digitized information is transmitted from the camera through the Ethernet cable to the interface card in the host computer where it is stored in RAM.

10. The application software retrieves the information from RAM, processes it, displays it, and/or stores it to a file according to user-defined settings.

1.3   Safety Related Symbols Used in This Manual

⚠ **CAUTION!** ————————————————

The use of this symbol on equipment indicates that one or more nearby items should not be operated without first consulting the manual. The same symbol appears in the manual adjacent to the text that discusses the hardware item(s) in question.

⚠ **WARNING! RISK OF ELECTRIC SHOCK!** ————

The use of this symbol on equipment indicates that one or more nearby items pose an electric shock hazard and should be regarded as potentially dangerous. This same symbol appears in the manual adjacent to the text that discusses the hardware item(s) in question.

1.4   Grounding and Safety

The PI-MAX4 and power supply are of Class I category as defined in IEC Publication 348 (Safety Requirements for Electronic Measuring Apparatus.) They are designed for indoor operation only. Before turning on the power supply, the ground prong of the power cord plug must be properly connected to the ground connector of the wall outlet. The wall outlet must have a third prong, or must be properly connected to an adapter that complies with these safety requirements.

WARNINGS!

1. If the PI-MAX4 camera system is used in a manner not specified by Princeton Instruments, the protection provided by the equipment may be impaired.

2. If the equipment is damaged, the protective grounding could be disconnected. Do *not* use damaged equipment until its safety has been verified by authorized personnel. tampering with its operation is also prohibited.

Inspect the supplied power cord. If it is not compatible with the power socket, replace the cord with one that has suitable connectors on both ends.

WARNING! RISK OF ELECTRIC SHOCK!

The PI-MAX4 has internal power supplies that generate hazardous (and potentially lethal) voltages. It contains no user-serviceable parts. Do not attempt to operate it with the covers removed.

WARNING!

Replacement power cords or power plugs must have the same polarity and power rating as that of the original ones to avoid hazard due to electrical shock.

1.4.1   Intensifier Modes and Safety

WinX Applications

The Experiment Setup **Main** screen in WinX applications allows you to select one of two intensifier modes: **Gate Mode** or **Safe Mode**. In **Gate Mode**, the photocathode is biased on only for the time that each gate pulse is applied. As a result, the tolerance to room light is higher in gated operation, but the risk of damaging overload from intense light sources such as lasers remains. In fact, intense light sources in gated experiments can cause spot damage that would be undetected by the alarm circuit. In **Safe Mode**, the photocathode is continuously biased OFF and the intensifier is as safe as it can be.

LightField

In LightField, you can enable or disable the intensifier on the **Common Acquisition Settings** expander. When the intensifier is enabled, the camera can be gated; when disabled, the photocathode is continuously biased OFF and the intensifier is as safe as it can be.

> **NOTE:**
>
> In order for gating to occur, the I.I.T. switch on the back of the PI-MAX4 must also be in the **ON** position.

1.4.2   Audible Alarm

> **NOTE:**
>
> It is normal for the alarm to sound briefly when the system is initially turned on.

To reduce the risk of camera damage, the PI-MAX4 camera is equipped with an audible alarm in the camera, activated when the intensity of light falling on the image intensifier exceeds a preset threshold. While the alarm is sounding, the photocathode is disabled. Immediately switch the **I.I.T.** switch on the back of the PI-MAX4 to the **OFF** position. Cover the camera window and only switch the **I.I.T.** switch to **ON** after the illumination level has been lowered. If the alarm sounds continuously even when the illumination level is adequately low, shut the system down and contact the factory for guidance.

> ⚠ **CAUTION!**
>
> Discontinue operation and contact the factory at once if sporadic or continuous unwarranted alarms occur. They may indicate intensifier damage or another situation that requires immediate attention.

1.4.3   High Intensity Light Damage

WARNING! ────────────────────────────────

When biased ON, intensified CCD cameras, such as the PI-MAX®4 can be irreparably damaged if continuously exposed to light levels higher than twice the A/D saturation level. Therefore, it is **critical** that conditions **not** be created which could result in damage to the intensifier. Although intensified cameras are less prone to damage from **background light** when operated in gated mode, they are at **significant risk** to damage from high-intensity light sources such as a laser. High-intensity sources can damage the intensifier before protection circuits have time to respond, or even cause spot damage without the protection circuits acting at all. If a sustained alarm indication occurs when the camera is turned on, immediately switch the **I.I.T.** switch on the back of the PI-MAX4 to the **OFF** position. Cover the camera window and only switch the **I.I.T.** switch to **ON** after the illumination level has been lowered.

────────────────────────────────

If the alarm sounds continuously even when the illumination level is adequately low, shut the system down and contact the factory for guidance.

1.5   Precautions

To prevent permanently damaging the system, please observe the following precautions:

- Always switch off and unplug the PI-MAX4 power supply before changing your system configuration in any way.
- Whenever you turn the PI-MAX4 power supply OFF, be sure to leave it OFF for at least 30 seconds before switching it back ON. If you switch it ON too soon, a fault logic state is established that causes the overload alarm to sound continuously.
- The CCD array is very sensitive to static electricity. Touching the CCD can destroy it. Operations requiring contact with the device can only be performed at the factory.
- Never operate the camera cooled without proper evacuation or backfill. This could damage the CCD! Do not open the purge valve.
- Never connect or disconnect any cable while the PI-MAX4 system is powered on. Reconnecting a charged cable may damage the CCD.
- Never prevent the free flow of air through the equipment by blocking the air vents.

1.6   Cleaning and Maintenance

1.6.1   Cleaning the Camera

Although there is no periodic maintenance that *must* be performed on the PI-MAX4 camera, users are advised to wipe it down with a clean dust collecting cloth from time to time.

1.6.2   Cleaning Optical Surfaces – Protective Window

Optical surfaces may need to be cleaned due to the accumulation of atmospheric dust. We advise that the **drag-wipe** technique be used. This involves dipping a clean cellulose lens tissue into clean anhydrous methanol, and then dragging the dampened tissue over the optical surface to be cleaned. Do not allow any other material to touch the optical surfaces.

1.6.3   Flushing and Refilling the CCD Chamber

WARNING!

Under normal conditions the CCD chamber is sealed and backfilled so there is no danger of damage due to condensation.

WARNING!

Operating a PI-MAX4 that is no longer backfilled with dry air or dry nitrogen may result in condensation on the array that could cause irreversible damage. Such damage would not be covered by the Warranty.

Before a PI-MAX4 camera leaves the factory, its CCD chamber is backfilled with clean dry air or dry nitrogen. For proper operation it is essential that the integrity of the front enclosure be maintained*.*

In normal operation, the CCD chamber should remain sealed for the life of the camera and should require no maintenance to assure integrity. If it should ever happen that the CCD chamber becomes unsealed, contact the factory and arrange to return the camera to the factory where it can be properly flushed, backfilled and resealed again. Refer to Contact Information on page 312 for complete contact information.

1.7   Repairs

Save the original packing materials. Since the PI-MAX4 system contains no user-serviceable parts, repairs must be done by Princeton Instruments. Should a system need repair, contact Princeton Instruments customer support for instructions. Refer to Contact Information on page 312 for complete contact information.

Use the original packing materials whenever shipping the system or system components.

1.8   About this Manual

This section provides information about the organization of this manual.

1.8.1   Conventions Used in this Manual

WinX is a generic term for WinView/32, WinSpec/32, and WinXTest application software.

In this manual, **detector** and **camera** are used interchangeably.

Most features supported by the PI-MAX4 are also supported by the PI-MAX4-RF and PI-MAX4: EM family. Therefore, **PI-MAX4** is used generically throughout this manual unless a distinction must be made between specific camera types.

> **NOTE:**
>
> The PI-MAX4-RF does not support picosecond gating or MCP gating.

In many instances, WinX and LightField use different terms for the same functions or parameters. Unless the topic is specifically for LightField or WinX, curly brackets { } are used to denote a LightField term or location. When the topic applies to both application programs, the WinX term will be followed by the {LightField term}: for example, when **Continuous Cleans** is used, it will be followed by **{Clean Until Trigger}**. This convention is also used when a location for setting a parameter is mentioned: for example, the desired camera temperature is set on the **Detector Temperature** dialog {**Sensor** expander}.

1.8.2   Manual Organization

This manual provides the user with all the information needed to install a PI-MAX4 Intensified CCD camera and place it in operation. Topics covered include a detailed description of the camera, installation and setup, first time data acquisition, tips and tricks, microscopy applications, temperature control and more. A brief description of each chapter and appendix is provided:

- Chapter 1, Introduction, provides an overview of the PI-MAX4 camera. Topics include a description, theory of operation, and specifications.
- Chapter 2, System Installation, cross-references system setup actions with the relevant manuals and/or manual pages. It also contains system layout diagrams.
- Chapter 3, System Setup, provides detailed directions for installing and setting up the PI-MAX4 for both spectroscopy and imaging.
- Chapter 4, First Light, provides abbreviated directions for getting your PI-MAX4 into operation as soon as possible.
- Chapter 5, Gate Mode Operation, provides information about experiment setup, temperature control, background subtraction, array readout, binning, and digitization when operating in Gate Mode.
- Chapter 7, WinX and Gated Operation, discusses issues specific to using WinX and operating the PI-MAX4 system in gate mode.
- Chapter 6, LightField and Gated Operation, discusses issues specific to using LightField and operating the PI-MAX4 system in gate mode.
- Chapter 8, Timing Generator, discusses and illustrates the trigger modes available when operating the system in gate mode.
- Chapter 10, WinX and Dual Image Feature, discusses using WinX with the mode specifically designed for capturing a pair of gated images in rapid succession.

- Chapter 9, LightField and Dual Image Feature, discusses using LightField with the mode specifically designed for capturing a pair of gated images in rapid succession.
- Chapter 11, MCP Gating Option, discusses how to set up a PI-MAX4 that has an installed MCP Gating board.
- Chapter 12, Picosecond Gating Option, discusses how to set up a PI-MAX4 that has an installed Picosecond board.
- Chapter 13, PI-MAX4: 1024i-RF and RF Modulation, discusses how to set up a PI-MAX4: 1024i-RF camera for RF modulation.
- Chapter 14, PI-MAX4: EM Family, discusses emICCD cameras, Electron Multiplication, and the use of Kinetics.
- Chapter 15, Tips and Tricks, discusses a number of issues that can have a bearing on getting good experimental results.
- Chapter 16, Component Descriptions, describes the PI-MAX4 camera and other system components. Includes descriptions of connectors and other front and rear panel features.
- Chapter 17, Troubleshooting, provides information regarding possible system problems.
- Appendix A, Technical Specifications, provides general specifications as well as operating environment and internal pulser specifications.
- Appendix B, Outline Drawings, includes outline drawings for the PI-MAX4 camera, the PI-MAX4 power supply, and the CoolCUBE$_{II}$ coolant circulator.
- Appendix C, WinX/LightField Cross Reference, includes two alphabetically sorted tables (WinX to LightField and LightField to WinX) that cross reference terms used in the two applications.
- Appendix D, Extender Bracket Kit, explains how to use this kit to mount the PI-MAX4 to any laboratory table with either 25 mm or 1 inch hole spacing.
- Appendix E, C- and F-Mount Information, discusses focusing of an F-mount adapter and focusing of F-mount and C-mount lenses.
- Appendix F, Spectrograph Mount Information, provides instructions for the mounting a PI-MAX4 camera with a spectroscopy adapter to an Acton SpectraPro Series or IsoPlane spectrograph. Additional instructions describe how to perform rotational alignment and focusing of the camera to the spectrograph optics.
- Appendix G, Accessories, provides information about available adapter kits and accessories, include procedures for changing the adapter on the front of the PI-MAX4 to another type when multiple adapters are available.
- Appendix H, Glossary, provides definitions of commonly used words and terms related to intensified camera characteristics and usage.
- Declaration of Conformity contains the Declarations of Conformity for PI-MAX4 systems.
- Warranty & Service details the warranties for Princeton Instruments equipment and software.

Chapter 2: System Installation

Table 2-1 describes the sequence of actions required to install a PI-MAX4 system and prepare to gather data. Where available, refer to the references specified with each step to obtain additional information.

Table 2-1:   PI-MAX4 System Installation Procedure (Sheet 1 of 2)

Action	For additional information, refer to…
1. If the system components have not already been unpacked, unpack them and inspect their carton(s) and the system components for in transit damage.	Chapter 3, System Setup, on page 33
2. Verify that all system components have been received.	Chapter 3, System Setup, on page 33
3. If the camera will be used on a spectrograph, mount it to the equipment using the required adapter(s.)	Appendix F, Spectrograph Mount Information, on page 285
4. If the appropriate interface card is not already installed in the host computer, install it and its drivers.	Section 3.6, Application Software Installation, on page 39
5. If the application software has not already been installed on the host computer, install it.	WinView User Manual, document number 4411-0046 WinSpec User Manual, document number 4411-0048 LightField User Manual, document number 4411-0125
6. With the PI-MAX4 power supply and computer power turned OFF, connect the Ethernet cable (GigE) to the PI-MAX4 and the interface card in the host computer.	
7. Make the following connections based upon the type of system being setup: • **Air-Cooled System** Plug the power supply into the rear of the camera and plug the power supply into the power source. • **Liquid-Cooled System** Make the hose and power connections to the camera and plug the circulator into the power source. Add coolant if necessary. Turn on the circulator.	Section 3.7, Connect the Circulator [Liquid-Cooled Cameras Only], on page 42.

Table 2-1:   PI-MAX4 System Installation Procedure (Sheet 2 of 2)

Action	For additional information, refer to…
8. If the photocathode will be cooled, connect the supplied PVC tubing to the hose barb on the front of the camera and to a **chilled** dry nitrogen source.	
9. Turn the PI-MAX4 power supply ON.	
10. Turn on the computer and launch either LightField or WinX. When the computer boots, it may prompt for the location of interface drivers. • LightField When LightField launches, it will detect the camera and automatically place its icon in the **Available Devices** area. When you move that icon to the **Experiment Devices** area, the default parameters will automatically be loaded into the expanders. • WinX If this is the first time using a WinX application, the Camera Detection wizard will automatically run. This wizard retrieves information from the camera and enters this information as the default parameters for the system.	Section 3.8, Configure Default Camera System Parameters, on page 44 LightField Users Manual (PDF) This is available in the Documents subdirectory of the location where LightField was installed. WinView User Manual, document number 4411-0046 WinSpec User Manual, document number 4411-0048
11. Verify the hardware setup information and, if necessary, edit the parameters. Enter the pulser information. Enter the experiment setup parameters. If using a spectrograph, enter or edit that setup information	LightField User Manual, document number 4411-0125 WinView User Manual, document number 4411-0046 WinSpec User Manual, document number 4411-0048
12. Set the target array temperature. The typical target temperature is -25°C.	Section 5.5.3, Setting the Temperature, on page 67
13. When the system reaches temperature lock, begin acquiring data in focus mode.	Section 4.6.4, Initial Data Acquisition, on page 59.
14. Adjust the focus for the best image or spectral lines. • When using LightField, use the **Align Spectrometer** function. • When using WinSpec/32, use the **Focus Helper** function.	Appendix E, C- and F-Mount Information, on page 281; Appendix F, Spectrograph Mount Information, on page 285.

2.1 System Configuration Diagrams

This section provides block diagrams of typical system configurations.

Figure 2-1: Typical PI-MAX4 System Diagram
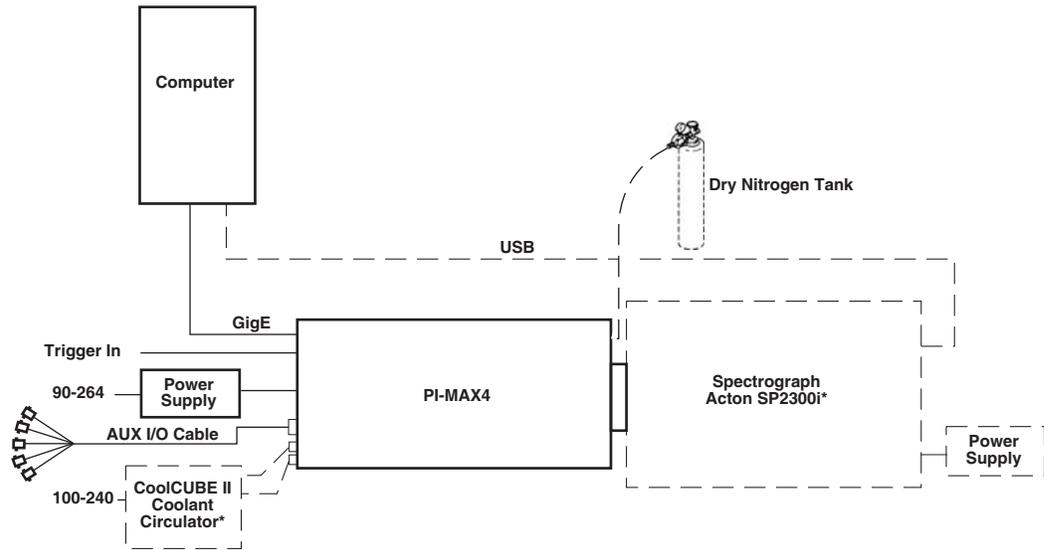
* Spectrograph, coolant circulator, and dry nitrogen tank connections are optional.

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Figure 2-2: Typical PI-MAX4: 1024i-RF System Diagram
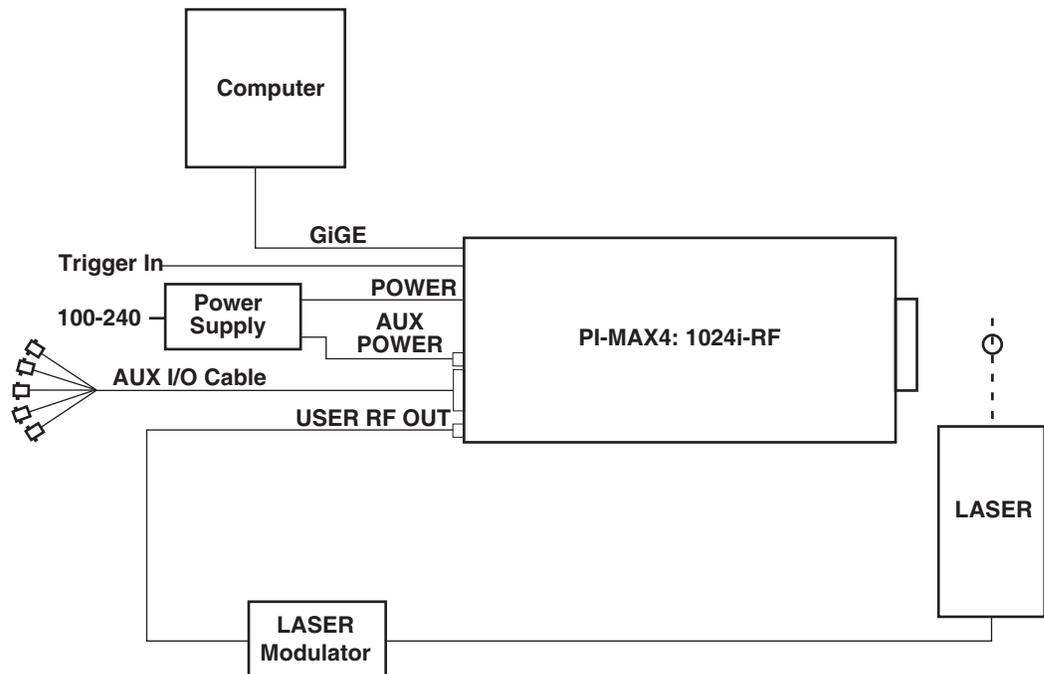
SPECTROGRAPH, COOLANT CIRCULATOR, AND DRY NITROGEN TANK CONNECTIONS
ARE OPTIONAL AND ARE NOT SHOWN IN THIS DIAGRAM.

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Chapter 3:   System Setup

This chapter provides general information and procedures for setting up a PI-MAX4 system for operation in both imaging and spectroscopic applications.

3.1   Dangers and Warnings

⚠ WARNING! RISK OF ELECTRIC SHOCK! ─────

Voltages inside the PI-MAX4 may exceed 6,000 Volts. To avoid possible hazard to personnel, use the instrument only according to the directions in this manual and only for the purposes for which it is designed. Never attempt to operate the PI-MAX4 with its covers removed.

WARNING! ─────────────────────

Image intensified cameras can be *destroyed* if exposed to excessive light levels. Princeton Instruments cannot take responsibility for PI-MAX4 camera damage due to misuse. Intensified cameras are particularly susceptible to overload damage when operated in conjunction with high-intensity light sources such as lasers. Spot damage can occur without the overload condition being detected.

The PI-MAX4 is equipped with an audible alarm and shutdown circuit to bias the photocathode OFF if excessive photocathode current is detected. The circuit automatically resets and biases the photocathode back on after about 0.5 seconds. The short-term protection provided will not prevent intensifier damage if excessive light is allowed to continuously fall on the intensifier. It is also possible for excessively bright spots to damage the intensifier tube without triggering the alarm.

3.2   Unpacking the System

During unpacking, check the system components for possible signs of shipping damage. If there are any, notify Princeton Instruments and file a claim with the carrier. Be sure to save the shipping carton for inspection by the carrier. If damage is not apparent but system specifications cannot be achieved, internal damage may have occurred in shipment. Please save the original packing materials so you can safely ship the camera system to another location or return it to Princeton Instruments for repairs if necessary.

3.3   Checking the Equipment and Parts Inventory

Verify that all equipment and parts required to set up the PI-MAX4 system have been delivered. A typical system consists of:

- **PI-MAX4 camera** (Gen II or Filmless Gen III.)
- **PI-MAX4 power supply**
- **Timing Generator:** Integrated into the PI-MAX4
- **Accessory Kit**
  Includes:
  — Light table mount extender;

  — AUX I/O Cable;

  — PVC tubing.
  If ordered, an additional mount or mounts will be included with a double-ended screwdriver with magnet top.
- **Computer Interface:** GigE
- **Computer:** Provided by user.
- **WinView/WinSpec or LightField CD**
- **User Manuals**
  Note that the LightField manual is supplied on the LightField CD and will be installed in the program directory when the program is installed.
- **Interface Dependent Components:**
  — Computer Interface GigE Cable

    Standard Ethernet Cable, 6050-0621, 5 meter.

    Other lengths up to 100 m are available.

  — Interface Card

    User-provided GigE interface card. (Intel Pro1000 recommended.)
- **System Dependent Components**
  CoolCUBE$_{II}$ Coolant Circulator and Coolant Tubing

If there are any problems, contact the Princeton Instruments Customer Support department. Refer to Contact Information on page 312 for complete contact information.

3.4   General System Requirements and Information

This section provides general information about PI-MAX4 system requirements.

> **REFERENCES:** —————————————————————————————
> For detailed technical specifications, refer to Appendix A,
> Technical Specifications, on page 255.

3.4.1   Ventilation

A PI-MAX4 System requires the following ventilation conditions:

- Camera
  Allow at least one-inch clearance for side and rear air vents.

  There are internal fans located behind an intake opening in the rear panel. Their purpose is simply to cool the camera and TE-cooler. The fans run continuously whenever the camera is powered. Air enters the through the openings in the rear panel and is exhausted through ventilation openings on the side panels. It is important that there be an adequate airflow for proper functioning.

  As long as both the camera's intake ventilation openings and the fan exhaust opening remain unobstructed, the camera will remain quite cool.

- Power Supply
  There is an internal fan located at the rear panel behind an exhaust opening. Its purpose is simply to cool the power supply electronics. This fan runs continuously whenever the power supply is powered. Air enters the through ventilation openings in the side panels, flows past the warm electronics, and is drawn out the rear by the fan. It is important that there be an adequate airflow for proper functioning. As long as both the intake ventilation openings and the fan exhaust opening remain unobstructed, the power supply will remain quite cool.

3.4.2   Power Specifications

Camera: The PI-MAX4 camera receives its power from the self-switching power supply which in turn plugs into a source of AC power.

Power Supply: The plug on the power cord supplied with the system should be compatible with the line-voltage outlets in common use in the region to which the system is shipped. If the power cord plug is incompatible, a compatible plug should be installed, taking care to maintain the proper polarity to protect the equipment and assure user safety.

> ⚠ **CAUTION!** ————————————————————————————————
> Whenever the PI-MAX4 power supply is turned OFF, be sure it
> remains OFF for a **minimum** of 30 seconds before switching it
> back ON. If it is switched on too soon, a fault logic state is
> established that causes the overload alarm to sound
> continuously.

3.4.3   Host Computer Specifications

Host Computer specifications vary based on which data acquisition software is being used. This section provides minimum host computer specifications by software package.

NOTES:

1. Computers and operating systems undergo frequent revisions. The following information is intended to provide an approximate indication of the computer requirements. Contact the factory to confirm specific requirements.

2. The specifications listed are the MINIMUM required for a PI-MAX4 camera. A faster computer with 2 GB (or more) RAM and a fast hard drive (e.g., 10,000 rpm,) will greatly improve system performance during live mode operations.

3.4.3.1   *WinX Host Computer Requirements*

When running WinX data acquisition software, the host computer must meet, or exceed, the following specifications:

- **32-bit** Operating System
    - — Windows® XP (SP3 or later,)
    - — Windows Vista®, or
    - — Windows® 7;
- 2 GHz Pentium® 4 (minimum)
- 1 GB RAM (minimum)
- CD-ROM drive
- At least one unused PCI card slot (32-bit) (PCI 2.3 compliant 32-bit 33/66 MHz bus)
- Super VGA monitor and graphics card
  Supporting at least 65535 colors with at least 128 Mbyte of memory.

NOTE:

Memory requirement is dependent on desired display resolution.

- 10,000 RPM (recommended) hard disk with a minimum of 1 GB available space. A complete WinX installation requires approximately 50 MB of space. The remaining space is required for data storage, and is dependent on the number and size of images/spectra collected.

NOTE:

Disk level compression programs are not recommended.

- Mouse or other pointing device.

3.4.3.2 LightField Host Computer Requirements

When running LightField data acquisition software, the host computer must meet, or exceed, the following specifications:

- **64-bit** Operating System

    — Windows Vista®;

    — Windows® 7.

- 2 GHz Pentium® 4 (minimum)
- 1 GB RAM (minimum)
- CD-ROM drive
- At least one unused PCI card slot (32-bit) (PCI 2.3 compliant 32-bit 33/66 MHz bus)
- Super VGA monitor and graphics card
  Supporting at least 65535 colors with at least 128 Mbyte of memory.

NOTE:

> Memory requirement is dependent on desired display resolution.

- 10,000 RPM (recommended) hard disk with a minimum of 1 GB available space. A complete LightField installation requires approximately 50 MB of space. The remaining space is required for data storage, and is dependent on the number and size of images/spectra collected.

NOTE:

> Disk level compression programs are not recommended.

- Mouse or other pointing device.

3.5 Mounting the Camera

This section provides information necessary to mount PI-MAX4 camera for various applications.

3.5.1 Imaging Applications

The camera is supplied with the lens mount specified when the system was ordered, normally either a screw-type C-mount lens or a bayonet type F-mount lens, allowing a lens of the corresponding type to be mounted quickly and easily. The installed mount is secured by four (4) Phillips head screws which must be removed to change mounts.

REFERENCES:

For additional information refer to:
- Appendix E, C- and F-Mount Information, on page 281;
- Appendix F, Spectrograph Mount Information, on page 285;
- Appendix G, Accessories, on page 293.

The camera can be mounted at any attitude or angle but additional camera support may be required. The camera can rest on any secure surface. Take care not to block the ventilation openings.

⚠ CAUTION!

In the case of cameras equipped with F-mount, do not mount the camera in the **nose-up** operation where the lens mount would be required to hold the camera's weight. The F-mount is not designed to sustain the weight of the camera in this orientation and the camera could pull free. **You must provide additional support for the camera.**

Should the camera be mounted in the nose-up position beneath a table, take care to protect the mounting components from lateral stresses, such as might occur should someone accidentally bump the camera with a knee while working at the table. One solution to this problem would be to install a barrier between the camera and operator to prevent any accidental contact.

There are no special constraints on nose-down operation. Again, however, good operating practice might make it advisable to take steps to prevent accidental contact from unduly stressing the mounting components. Be sure liquid connections do not leak in this orientation.

WARNING!

Always begin with the lens stopped all the way down (i.e., the largest f/ stop number,) to minimize the risk of overloading the intensifier.

3.5.2   Spectroscopy Applications

The camera must be properly mounted to the spectrograph to achieve the highest resolution. In the correct orientation, the text on the back of the camera should be right side up. Take care not to block the ventilation openings.

REFERENCES: ——————————————————

For additional information, refer to:

- Quick Start: Mounting a PI-MAX3 or PI-MAX4 (3.60 3-hole Slotted) to an Acton SpectraPro Series Spectrograph;
- Quick Start: Princeton Instruments Camera with Slotted Flange to an IsoPlane SCT-320 Spectrograph;
- Instructions provided with the system;
- Appendix F, Spectrograph Mount Information, on page 285.

3.6   Application Software Installation

This section provides detailed procedures for the installation of supported application software.

3.6.1   WinX Applications

This section provides the installation procedure for WinX application software.

NOTES: ——————————————————

1. Install the GigE Adapter card BEFORE installing the WinView/32 or WinSpec/32 application software.

2. The interface cable should remain disconnected from the camera until after WinView/32 or WinSpec/32 (version 2.5.25 or higher) has been successfully installed.

Perform the following procedure to install WinX on the host computer:

1. Insert the WinView/32 or WinSpec/32 software installation CD into the CD drive on the host computer. The installation program will automatically launch.

2. When the **Select Installation Type** dialog is displayed, select the desired type of installation.

   - **Typical** installs all required drivers and the most commonly installed program files;
   - **Complete** installs all available application drivers and features;
   - **Custom** is used to select specific features and drivers for installation, as well as specifying a custom installation directory. This is only recommended for use by advanced users.

   Figure 3-1 illustrates a typical WinView/32 Setup dialog.

Figure 3-1:   Typical WinView/32 Setup Dialog
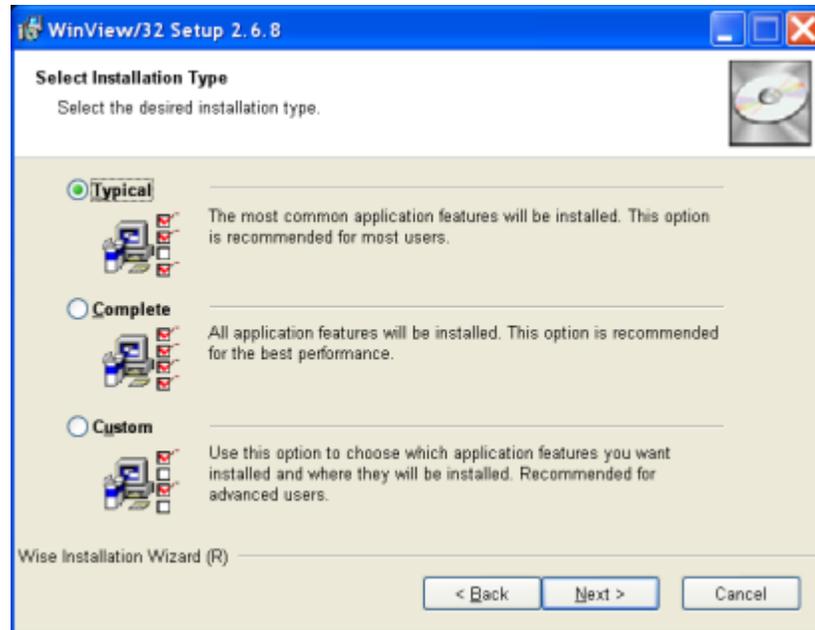
4411-0137_0005

3. Click **<u>Next</u> >** to continue with the installation, and continue to follow on-screen prompts.

4. Once the installation has been completed, connect the camera to the host computer and turn on the camera's power supply.

5. Reboot the host computer.

    Windows will automatically detect the newly-installed GigE card.

> 📖 **REFERENCES:** ━━━━━━━━━━━━━━━━━
>
> For additional information, refer to Section 4.6, WinX First Light Instructions, on page 55.

3.6.2 LightField Applications

This section provides the installation procedure for LightField application software.

> 🔍 **NOTE:** ───────────────────────────────
>
> Install the GigE Adapter card BEFORE installing the
> LightField application software.

Before beginning to install LightField, verify that:

- The operating system on the desired host computer is either Windows Vista (64-bit) or Windows 7 (64-bit);
- A GigE adapter card has been installed;
- The host computer is connected to the Internet. Internet connection may be required for product activation.

Perform the following procedure to install LightField on the host computer:

1. Insert the LightField Installation CD into the CD drive on the host computer, and follow the on-screen prompts.

   Figure 3-2 illustrates a typical InstallShield Wizard dialog.

Figure 3-2: Typical LightField InstallShield Wizard Dialog

4411-0137_0006

2. After the installation has been completed, reboot the computer.
3. Connect the PI-MAX4 system components to the host computer and apply power.
4. Launch LightField, activate it, and begin setting up your experiment.

> 📖 **REFERENCES:** ───────────────────────────────
>
> For additional information, refer to Section 4.5, LightField
> First Light Instructions, on page 49.

3.7   Connect the Circulator [Liquid-Cooled Cameras Only]

For liquid-cooled cameras, the CoolCUBE$_{II}$ circulator provides a vibration-free method of heat removal.

REFERENCES:

For additional information about coolant hoses, refer to Section A.7, CoolCUBE$_{II}$ Circulator Specifications, on page 261.

Figure 3-3 illustrates a typical CoolCUBE$_{II}$ circulator.

Figure 3-3:   Typical CoolCUBE$_{II}$ Circulator
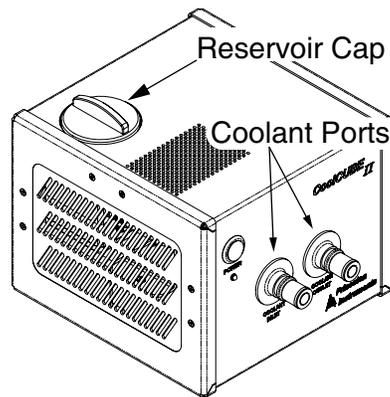
4411-0137_0007

Perform the following procedure to connect a PI-MAX4 to a CoolCUBE$_{II}$ circulator:

1.   Make sure the camera and the circulator power switches are turned off.

2.   Make sure the circulator is 6 inches (150 mm) or more below the camera. The vertical distance should not exceed 10 feet (3 m.) Typically, the camera is at table height and the circulator is on the floor.

3.   Make the coolant connections between the circulator and the camera. It does not matter which hose from the circulator is plugged into a coolant port on the camera.

4.   It is recommended that hoses be secured to the camera hose barbs with the clamp supplied.

NOTES:

1.   Verify that there are no kinks in the hoses that impede the coolant flow. Lack of sufficient flow can seriously harm the camera and any resulting damage is not covered under warranty.

2.   Damage caused by water leaking into the camera voids the warranty.

5.   Unscrew the reservoir cap (on top of the CoolCUBE$_{II}$) and make sure that the coolant reservoir contains coolant. If additional coolant is required, fill with a 50:50 mixture of water and ethylene glycol.

6.   Screw the reservoir cap back in.

7. Plug the circulator into an appropriate power source (i.e., 100-240 V_{AC}, 47-63 Hz.)

8. Turn the circulator on. Make sure there are no leaks or air bubbles in the hoses.

> **NOTE:** ────────────────
>
>   Small air bubbles (about the size of bubbles in soda) are
>   common in the CoolCUBE$_{II}$ particularly following start up and
>   do not prevent proper operation.

  • If there are no problems, proceed to step 9.
  • If leaks or large air bubbles are observed, turn the circulator off and correct the
    problem(s) by securing the hoses or adding more coolant to the reservoir.
    Turn the circulator back on. Recheck and if there are no problems, proceed to
    step 9.

9. Turn the camera on.

10. Launch the application software.

3.8 Configure Default Camera System Parameters

This section describes the initial configuration of default camera parameters.

3.8.1 WinX (Versions 2.5.25.X or higher)

Perform the following procedure to configure default WinX system parameters:

1. Make sure the PI-MAX4 is connected to the host computer and that its power supply is turned ON.

2. Launch the WinX application.
   - The **Camera Detection Wizard** will automatically run if this is the first time a Princeton Instruments WinX application (WinView/32, WinSpec/32, or WinXTest/32) has been installed with a supported camera.
   - If simply installing a new camera type, click on the **Launch Camera Detection Wizard…** button on the **Controller/CCD** tab to launch the wizard.

3. When the **Welcome** dialog is displayed, the check box should remain unchecked. Click **Next**.

   See Figure 3-4.

Figure 3-4: Typical WinX Camera Detection Wizard Dialog

4411-0137_0008

4. Follow the on-screen prompts to perform the initial hardware setup.

   The wizard automatically populates Hardware configuration parameters with default values and provides the opportunity to acquire a test image to verify the system is working properly.

   > **NOTE:**
   >
   > For step-by-step procedures describing basic system operation within WinX, refer to Section 4.6, WinX First Light Instructions, on page 55.

3.8.2 LightField

Perform the following procedure to configure default LightField system parameters:

1. Verify that PI-MAX4 is connected to the host computer, and that its power supply is turned on.

> **NOTE:**
>
> If configuring a spectroscopy system, the spectrograph must also be connected and turned on.

2. Launch LightField.

3. As LightField is launching, it will detect all available devices and automatically load appropriate icons into the **Available Devices** area of the **Experiment** workspace.

4. When an icon is dragged into the **Experiment Devices** area, appropriate expanders will be loaded into the **Experiment Settings** stack on the left-hand side of the window.

> **NOTE:**
>
> For step-by-step procedures describing basic system operation within WinX, refer to Section 4.5, LightField First Light Instructions, on page 49.

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Chapter 4:   First Light

This chapter provides two procedures (one for WinX and one for LightField) that can be used to verify PI-MAX4 system operation. To reduce setup complexity, these procedures are run in **Imaging Mode** and SuperSYNCHRO™ **Internal Trigger Mode**. All of the setup can be performed under normal lighting. Since these first light procedures do not require a spectrograph, instructions for cabling and mounting of a spectrograph are not included.

> **NOTE:**
>
> Issues that could be of importance in some applications are omitted in this chapter for the sake of brevity. General application issues are addressed in Chapter 5 and those that are specific to Gate Mode are addressed in the appropriate chapters.

4.1   Required Equipment and Cables

The equipment and cables listed below are required to set up and run the PI-MAX4 camera system in accordance with the procedures described in this chapter.

- Princeton Instruments PI-MAX4 camera with C-mount adapter;
- User-supplied C-mount lens (with smallest aperture of f/16 or f/22);
- PI-MAX4 power supply;
- Computer equipped with a GigE Ethernet interface card;
- Standard Ethernet cable;
- Application software (WinX/32 or LightField.)

4.2   Cable Connections

> **WARNING!**
>
> All system components must be turned off before connecting or disconnecting cables.

The following cabling configuration is used when operating in Gating Mode with an internal trigger.

1. Connect the PI-MAX4 power supply to the rear of the camera and to the AC power source.
2. Connect the **GigE** cable (6050-0621) from the PI-MAX4 **GigE** connector to the computer's **GigE** Interface card connector.

4.3 Before Turning on the System

Before turning on the system:

- Set the PI-MAX4 **I.I.T.** On/Off switch to OFF.
- Confirm that only room light will be present.
- If a C-mount adapter is not already mounted on the camera, refer to Section G.4, Standard C-, F-, and Spectroscopy-Mount Adapters, on page 294 for complete information and procedures.
- After changing mounts, screw in the lens and set the lens to its smallest aperture (i.e., f/16 or f/22.)
- Place a suitable non-light source target approximately 9 inches in front of the camera.

4.4 Turning on the System

WARNING!

Always begin with the lens stopped all the way down (largest f/ stop number) to minimize the risk of overloading the intensifier.

Perform the following procedure to turn on a PI-MAX4 system:

1. Turn on the PI-MAX4 power supply.

NOTE:

The PI-MAX4 overload alarm may sound briefly and then stop. This is normal and is not a cause for concern. However, if the alarm sounds continuously, even with no light entering the camera (or spectrograph,) something is wrong. Turn off the power and contact the factory for guidance.

2. Turn on the computer power.
3. Start the software application (WinView/32, WinSpec/32, or LightField as appropriate.)
4. Follow the appropriate first light instructions.

4.5   LightField First Light Instructions

This section provides step-by-step instructions for acquiring an imaging measurement in LightField for the first time. The intent of this procedure is to gain basic familiarity with the operation of the system and to determine that it is functioning properly. Once basic familiarity has been established, operation with other operating configurations, ones with more complex timing modes, may be performed.

4.5.1   Assumptions

The following procedure assumes:

- The system has been set up in accordance with the instructions in the previous chapters.
- Previous sections of this chapter have been read;
- Familiarity with the LightField application software;
- The system is being operated in imaging mode;
- The target is a sharp image, text, or a drawing that can be used to verify that the camera is "seeing" and can be used to maximize focus.

4.5.2   Getting Started

Prior to performing any procedure within this chapter:

- Verify that a test target has been positioned approximately 9 inches in front of the camera;
- Power ON the camera (the power switch is on the back of the power supply);
- Turn on the host computer;
- Launch LightField.

4.5.3   Parameter Configuration

NOTE:

> This procedure is based on LightField. Basic familiarity with the LightField software is assumed. If this is not the case, review the software manual or have it available while performing this procedure.

1. Once LightField has launched, an icon representing the camera should be visible within the **Available Devices** area. For example, in Figure 4-1, a PI-MAX4:1024x256 is shown.

Figure 4-1:   LightField Desktop: Available Devices
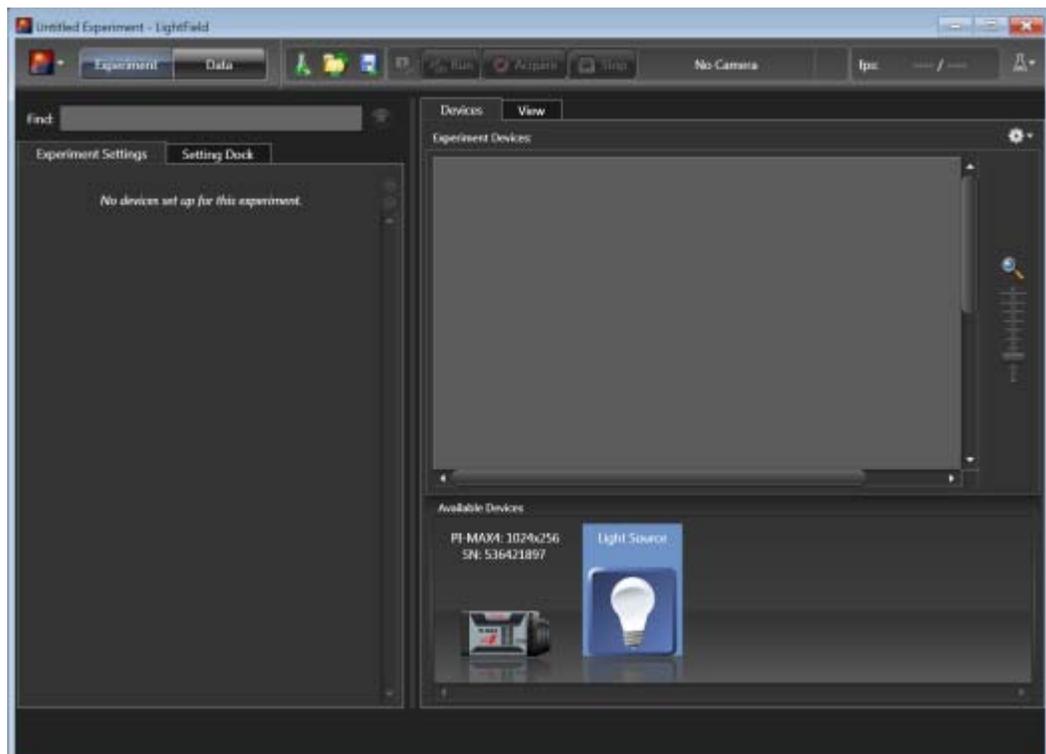
4411-0137_0017

2. Drag the desired camera icon into the **Experiment Devices** area of the desktop. See Figure 4-2.

Figure 4-2:   Camera Icon in Experiment Devices Area

4411-0137_0018

Once a camera has been placed in the **Experiment Devices** area, the **Experiment Settings** stack on the left displays several expanders, including the **SuperSYNCHRO Timing** expander just above the **Status** bar along the bottom of the application window. Since this is a new experiment, default settings for the camera are provided.

Within the **Status** bar are two icons which provide real-time temperature and intensifier status information.

- The Temperature status section ![-25°C Locked] reports the current temperature for the system, and whether the set temperature has been reached.

- The Intensifier status icon ![icon] indicates if the **I.I.T. Power** switch located on the rear of the camera is turned on and if the **Enable Intensifier** check box is checked.

Clicking on either of these icons opens a separate panel in which additional status information is provided. In addition, hyperlinks are provided to gain access to relevant expanders where configuration changes can be made.

4.5.4   Acquiring Data

Perform the following procedure to verify the system's ability to acquire data:

1. Verify that the **I.I.T. Power** switch on the rear of the camera is in the **ON** position

2. Verify that **Enable Intensifier** is selected on the **Common Acquisition Settings** expander.

3. Click on the **View** tab, located just above **Experiment Devices**, to change to the display area. See Figure 4-3.

Figure 4-3:   LightField Desktop View Area
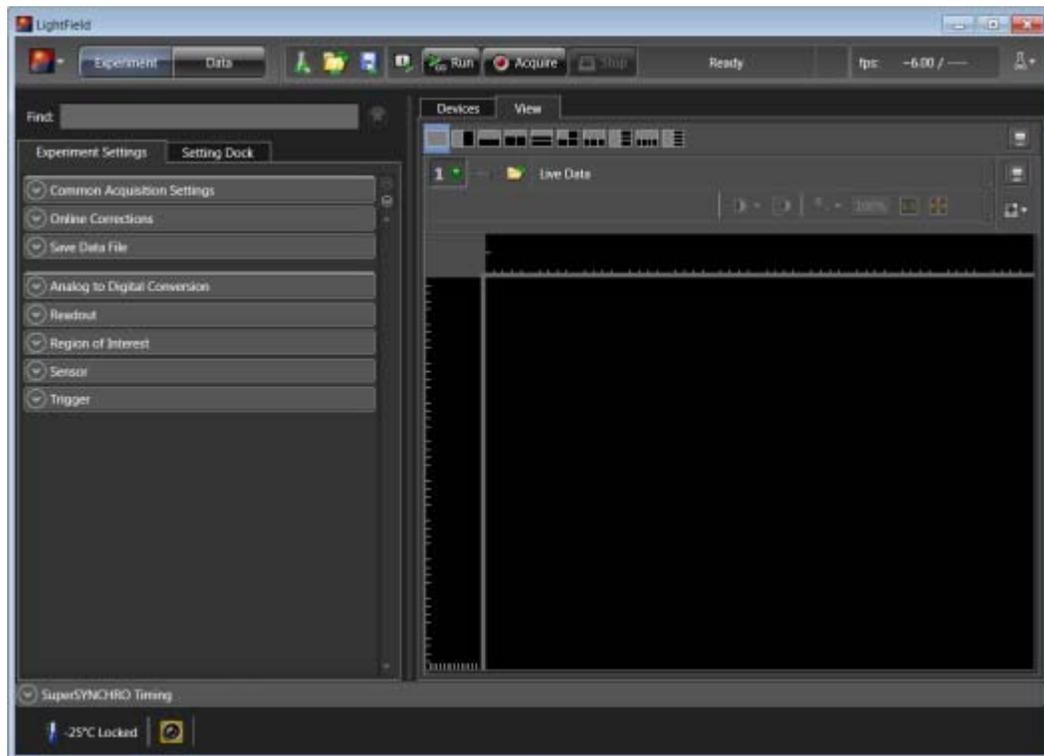
4411-0137_0019

4. Open the **SuperSYNCHRO Timing** expander (located above the Status bar.) See Figure 4-4.

Figure 4-4:   Typical SuperSYNCHRO Timing Expander
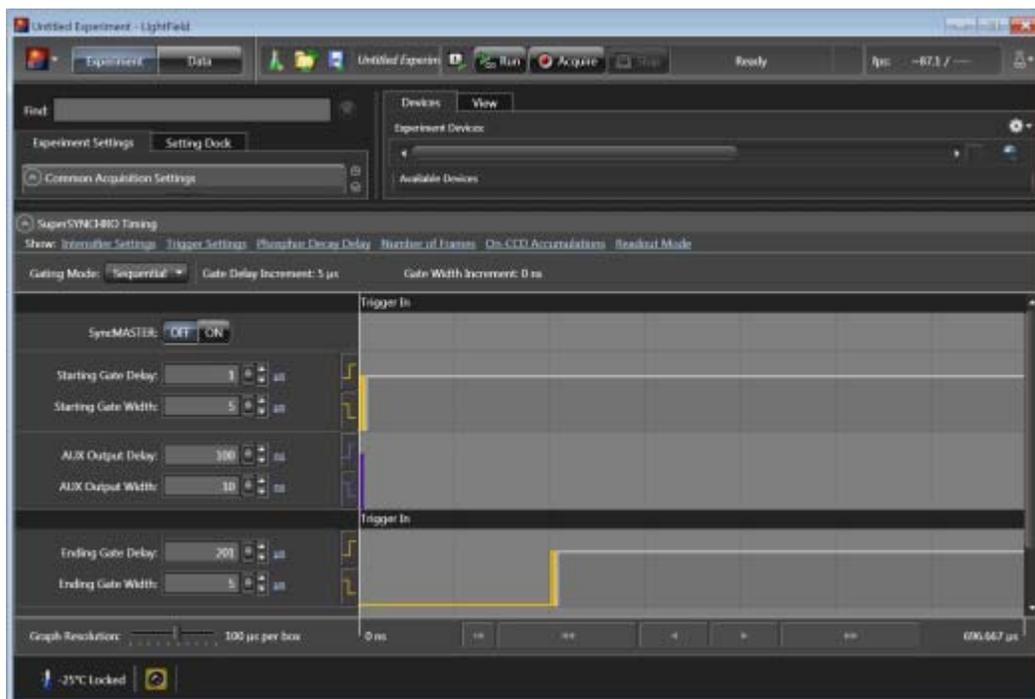
4411-0137_0078

5. Configure the following Gating parameters as desired:

> 📖 **NOTE:**
>
> The list of configuration parameters varies depending on the specific Gating Mode selected.

- Gating Mode;
- Starting Gate Delay;
- Starting Gate Width;
- Ending Gate Delay;
- Ending Date Width.
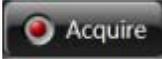
6. Click on the **Acquire** button [Acquire] to begin image acquisition.
   - If an image is displayed, PI-MAX4 is able to acquire an image.
     If the image is out of focus, reposition the target and/or rotate the lens. Click on **Acquire** to determine the degree to which the focus has changed.
   - If the image is upside down, change the image orientation using the **Online Corrections** expander.

   Figure 4-5 shows a properly oriented, in-focus image.

Figure 4-5: LightField View Area Displaying an Acquired Image
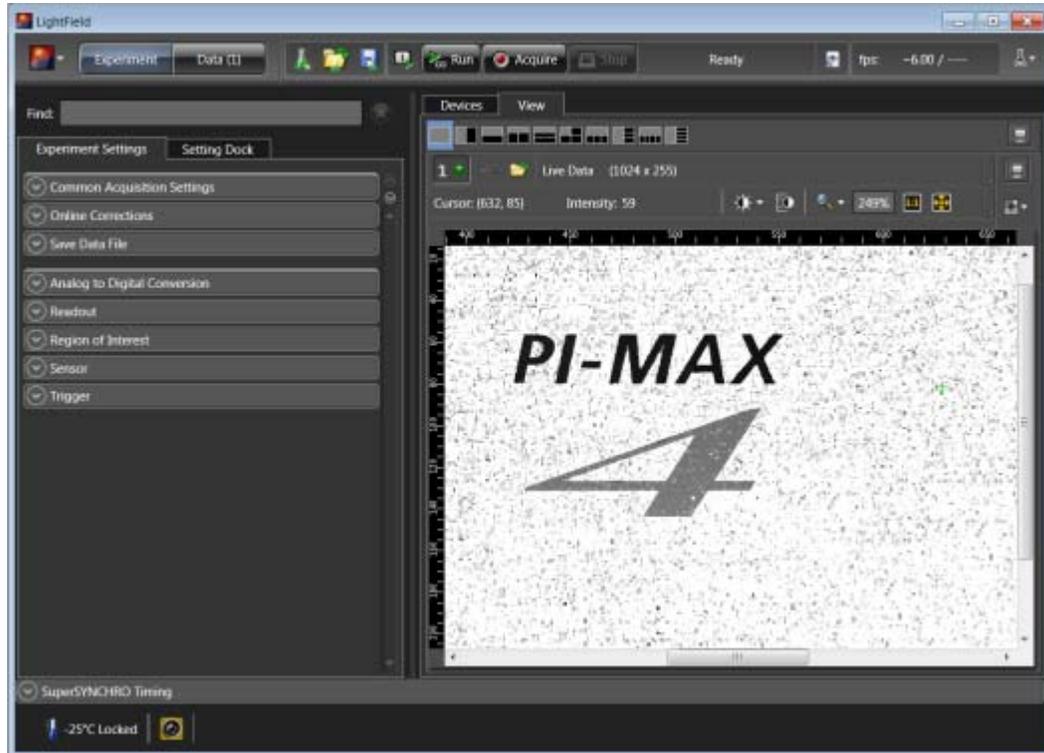
4411-0137_0020

4.5.5 Focusing

REFERENCES:

For complete information about focusing the PI-MAX4 camera when using C-, F-, or spectroscopy mounts, refer to:
- Section E.4, Focusing C- and F-Mount Lenses;
- Section F.3, Spectrograph-Camera Rotational Alignment and Focusing

4.6   WinX First Light Instructions

This section provides step-by-step instructions for acquiring an imaging measurement in WinX for the first time. The intent of this procedure is to help you gain basic familiarity with the operation of your system and to show that it is functioning properly. Once basic familiarity has been established, then operation with other operating configurations, ones with more complex timing modes, can be performed.

4.6.1   Assumptions

The following procedure assumes:

- The system has been set up in accordance with the instructions in the previous chapters.
- Previous sections of this chapter have been read.
- Familiarity with the WinX application software.
- The system is being operated in imaging mode.
- The target is a sharp image, text, or a drawing that can be used to verify that the camera is "seeing" and can be used to maximize focus.

4.6.2   Getting Started

Prior to performing any procedure within this chapter:

- Verify that a test target has been positioned approximately 9 inches in front of the camera;
- Power ON the camera (the power switch is on the back of the power supply);
- Turn on the host computer;
- Launch WinX.

4.6.3   Configuring the Software

Perform the following procedure to configure WinX:

1. From the **Setup** pull-down menu, select **Pulsers**.

   The **Pulsers** dialog is displayed, similar to that shown in Figure 4-6.

   Figure 4-6:   Typical WinX Pulsers Dialog

4411-0137_0009

2. Select the **SuperSYNCHRO** radio button, and then click on the **Setup Pulser…** button. The **SuperSYNCHRO** dialog is displayed, as shown in Figure 4-7.

Figure 4-7: Typical SuperSYNCHRO Dialog: Trigger In Tab
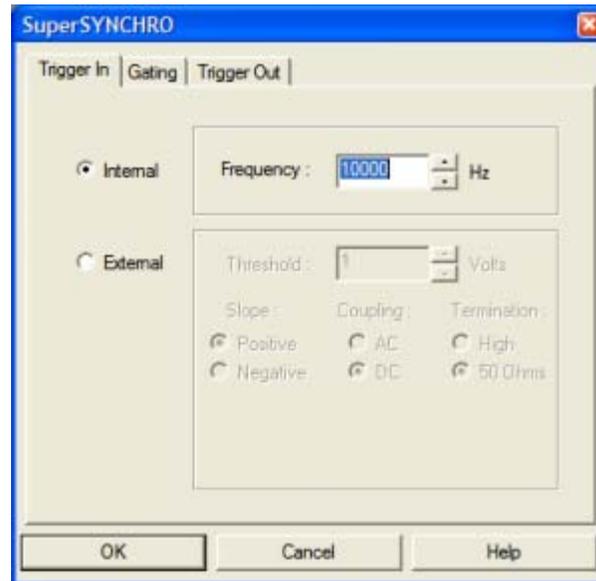
4411-0137_0010

3. On the **Trigger In** tab, verify the following settings:
   - **Internal** is selected;
   - **Frequency** = 10000 Hz.

4. Click on the **Gating** tab.

   Configure the Gating Mode by selecting **Repetitive**. See Figure 4-8.

Figure 4-8: Typical SuperSYNCHRO Dialog: Gating Tab
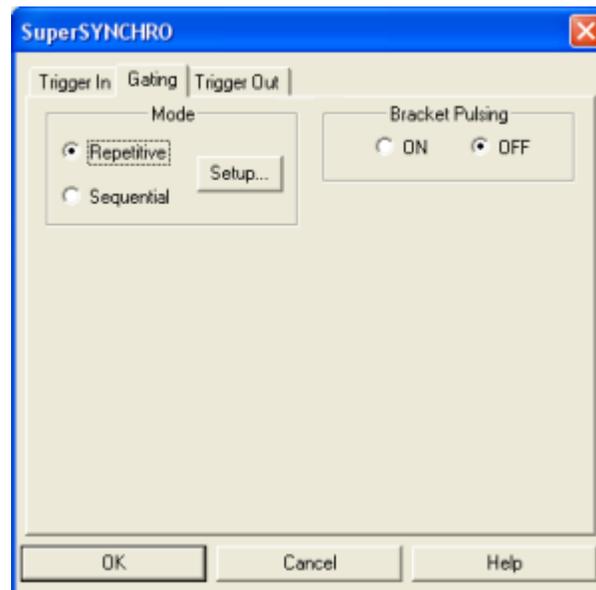
4411-0137_0011

5. Click **Setup…** to display the **Repetitive Gating Setup** dialog, similar to that shown in Figure 4-9.

Figure 4-9:   Typical Repetitive Gating Setup Dialog
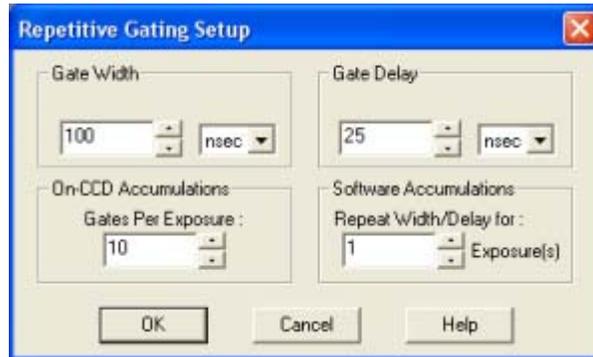
4411-0137_0012

6. Configure the following settings:
   - **Gate Width:** 50 ms;
   - **Gate Delay:** 10 ns;
   - **Gates per Exposure:** 1;
   - **Repeat Width/Delay:** 1.

7. Click **OK** to save the Repetitive Gating configuration settings and return to the **SuperSYNCHRO** dialog.

8. Click **OK** to save the **SuperSYNCHRO** configuration.

9. From the **Acquisition** pull-down menu, select **Experiment Setup**.

   The **Experiment Setup** dialog is displayed with the **Main** tab shown.

10. Configure the following parameters:

- **CCD Readout:** Use Full Chip;
- **Intensifier Gain:** 1;
- **Gate Mode:** Selected.

See Figure 4-10.

Figure 4-10: Typical Experiment Setup Dialog: Main Tab
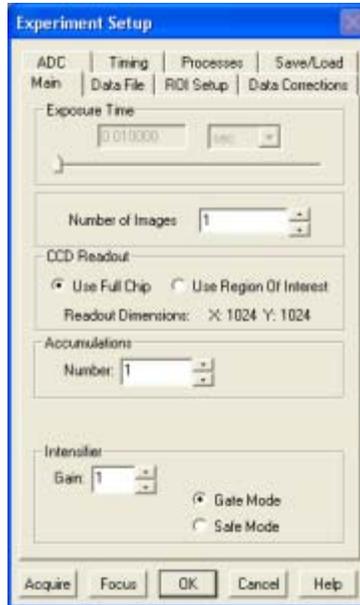
4411-0137_0013

11. Click on the **ADC** tab.

12. From the **Rate:** pull-down list of camera-specific frequencies, select a frequency that is closest to mid-range.

See Figure 4-11.

Figure 4-11: Typical Experiment Setup Dialog: ADC Tab
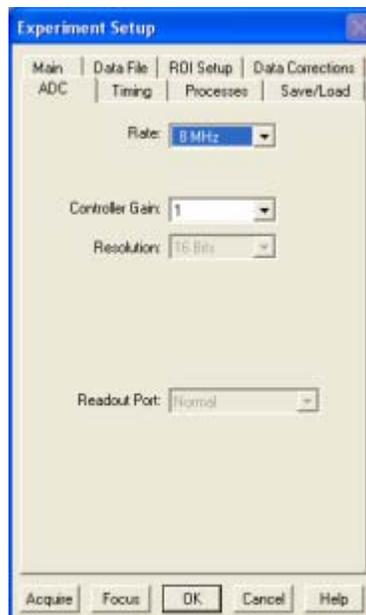
4411-0137_0014

13. **For WinSpec Applications:** Click on the **ROI Setup** tab and select **Imaging Mode**. See Figure 4-12.

Figure 4-12:　Typical Experiment Setup Dialog: ROI Setup Tab
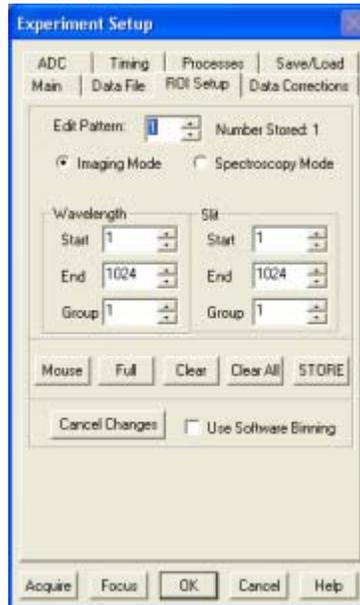
4411-0137_0015

14. Click **OK** to save the configuration settings and dismiss the **Experiment Setup** dialog.

4.6.4　Initial Data Acquisition

Perform the following procedure to begin initial data acquisition for a test image:

> **NOTE:**
>
> When using a C-mount lens, a PI-MAX4 will typically focus on an object at distance of approximately 9 inches [22.86 cm.]

1. Verify that room or ambient lighting is subdued.
2. Turn on the PI-MAX4 I.I.T.

> **NOTE:**
>
> The PI-MAX4 overload alarm may sound briefly and then stop. This is normal and is not a cause for concern. However, if the alarm sounds repetitively, even with no light entering the lens, something is wrong. Turn off the power and contact the factory for guidance.

3. From the host computer, click on the **Focus** button ⓕ or select **Acquisition —> Focus** from the pull-down menu. Data acquisition will begin and an acquired image should be displayed on the computer monitor.

- If an image is successfully acquired and displayed, it has been confirmed that the PI-MAX4 can acquire images.

  If the image is out of focus, reposition the target and/or rotate the lens and then click on **Acquire** to determine the degree to which the focus has been changed.

- If an image is not displayed, verify the software configuration settings and then try again to acquire a test image.

See Figure 4-13 for a sample image.

Figure 4-13: Sample Acquired Test Image

4411-0137_0016

4. Once it has been confirmed that the PI-MAX4 is able to acquire images, turn the PI-MAX4 I.I.T. switch OFF and close WinX.

📖 **NOTE:** ─────────────────

If the PI-MAX4 will not be used with the lens, replace the C-mount lens with the screw-in dust cover provided with the C-mount adapter.

If a different adapter, will be used, switch adapters at this point. Be sure to use the adapter's dust cover whenever the PI-MAX4 is not being used.

4.6.5 Focusing

📖 **REFERENCES:** ─────────────────

For complete information about focusing the PI-MAX4 camera when using C-, F-, or spectroscopy mounts, refer to:

- Section E.4, Focusing C- and F-Mount Lenses;
- Section F.3, Spectrograph-Camera Rotational Alignment and Focusing

Chapter 5: Gate Mode Operation

The purpose of the First Light chapter was to guide a user through initial system configuration and verification. The step-by-step procedures provided appropriate configuration settings without explaining why those settings had been selected.

This chapter provides detailed information about factors affecting **Gate Mode** operation of a PI-MAX4 system including:

- Dark charge;
- Clean cycles;
- Continuous cleans;
- Exposure modes;
- Readout;
- Digitization;
- Software binning; and
- Background subtraction.

Factors which pertain to a specific intensifier mode and pulser are described in the appropriate chapter.

5.1 Data Acquisition Sequence

When data is acquired, the CCD array is exposed to an incoming signal which is then integrated on the array. At the end of the exposure (may include multiple gates,) the charge from the array pixels must be read out, digitized, and transferred to the computer before the image from the array appears on the computer screen. This sequence is shown in Figure 5-1.

Figure 5-1:   Block Diagram: Signal Path in a Standard PI-MAX4 System
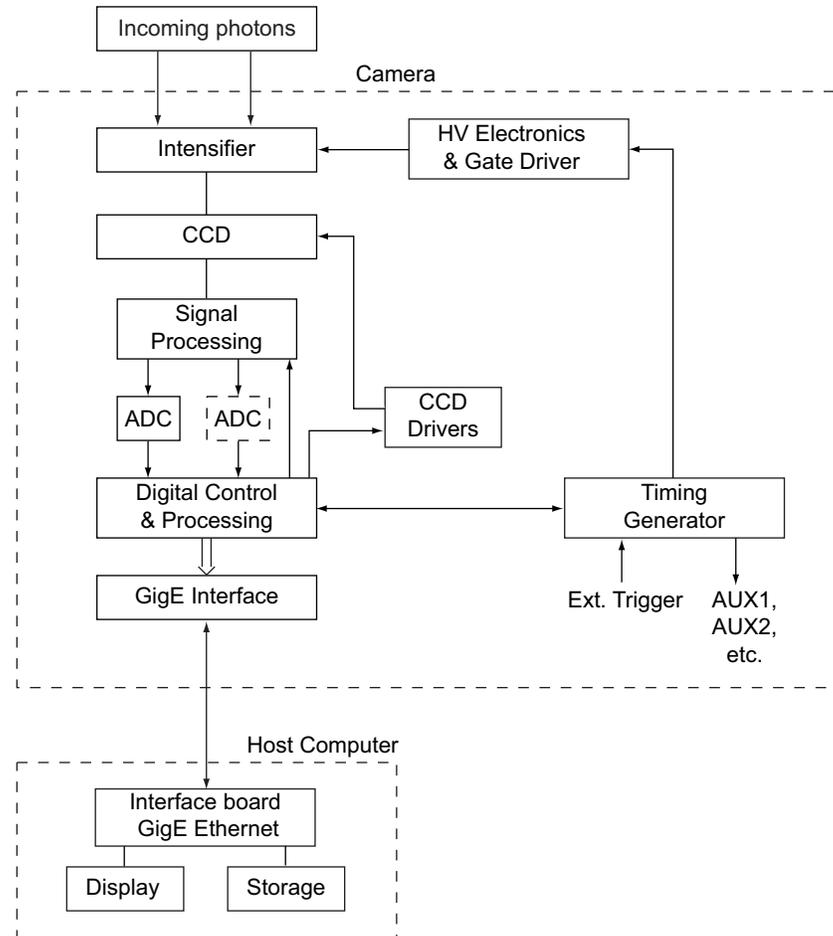
4411-0137_0021

5.2   WinX System On/Off Sequences

The following on/off sequences are specific to WinX and the Ethernet interface:

1. The PI-MAX4 power supply must be turned on before the WinX application software (WinView/32 or WinSpec/32) is opened to ensure communication between the controller and the computer. If the WinX application is opened and the PI-MAX4 power supply is off, many of the functions will be disabled and you will only be able to retrieve and examine previously acquired and stored data. You must close the WinX application software, turn on the power supply, and reopen the WinX application software before you can set up experiments and acquire new data.

2. The WinX application software must be closed before turning off the power supply. If you turn off the power supply before closing the WinX application software, the communication link with the PI-MAX4 will be broken. You can operate the program in a playback mode (i.e., examine previously acquired data,) but will be unable to acquire new data until you have closed the WinX application software, turned on the power supply, and then reopened the WinX application software.

5.3   Pre-Exposure Removal of Accumulated Charge

The purpose of the CCD array is to acquire a signal of interest that can then be digitized and transmitted to the host computer for storage, display, and post-processing. It will acquire signal whenever the camera has power, whether or not the intensifier is being gated to take an exposure. If the intensifier is off, dark charge will be the main source of signal accumulation on the array. To counteract this, clean cycles and continuous clean cycles are used to remove the dark charge while the camera is waiting to acquire the signal of interest. Dark charge, clean cycles, and continuous clean cycles are described in the paragraphs that follow.

5.3.1   Dark Charge

As soon as the PI-MAX4 camera is powered on, thermally-induced charge will begin integrating on the CCD array even if the photocathode is biased off. Because dark charge is thermally-induced, reducing the array temperature significantly reduces the rate at which this charge accumulates in the pixel wells. Even so, enough dark charge could accumulate in the pixels between data acquisitions to affect dynamic range at the beginning of an exposure. To prevent this from happening, clean cycles repeatedly shift and discard any signal that has integrated on the PI-MAX4 array while it is waiting for a Start Acquisition command from the host computer.

After the Start Acquisition command is received, a final clean cycle occurs and exposure begins. During the exposure, both the signal of interest and dark charge integrate on the array. The longer the exposure and the warmer the camera, the larger and less uniform the dark charge will appear. To minimize the dark charge contribution to the acquired signal, you should operate with the lowest temperature possible for your camera.

To further reduce the dark charge contribution to an acquired signal, you may be able to perform background subtraction, which subtracts a dark charge background from raw data acquired using the same experiment conditions. Refer to Section 5.7, Background Subtraction, on page 69 for additional information.

> **NOTE:**
>
> Do not be concerned about either the DC level of this background noise or its shape unless it is very high, i.e., > 1000 counts with 16-bit A/D. What you see is not noise. It is a fully subtractable readout pattern. Refer to Section 5.7, Background Subtraction, on page 69 for additional information.

> **WARNING!**
>
> If a sudden change in the baseline signal is observed, there may be excessive humidity in the camera's CCD enclosure. Turn off the controller **IMMEDIATELY**. Then, contact Princeton Instruments Customer Support for further instructions. Refer to Contact Information on page 312 for complete information.

5.3.2 Cleaning

The basic cleaning function is implemented by clean cycles. These cycles start when you turn the camera on and a clean pattern is programmed into the camera. Their purpose is to remove charge that accumulates on the array while the camera not acquiring data (i.e., exposing and reading out the array.) The timing diagram below is for an experiment set up to acquire three (3) images using Internal trigger mode selected on **SuperSYNCHRO Trigger In** tab {**Trigger** expander} and Gate Mode selected on **Experiment Setup Main** tab {In LightField, the equivalent of Gate Mode is active when **Enable Intensifier** is checked on the **Common Acquisition Settings** expander}. In Figure 5-2, clean cycles occur before the first exposure and after the last readout period. They do not need to occur between exposures since each readout cleans the array before the next exposure starts.

Figure 5-2:   Clean Cycles in Internal Trigger Mode of Operation

ET = exposure time set in Experiment Setup
t_c = 3 msec shutter compensation for Electronic shutter
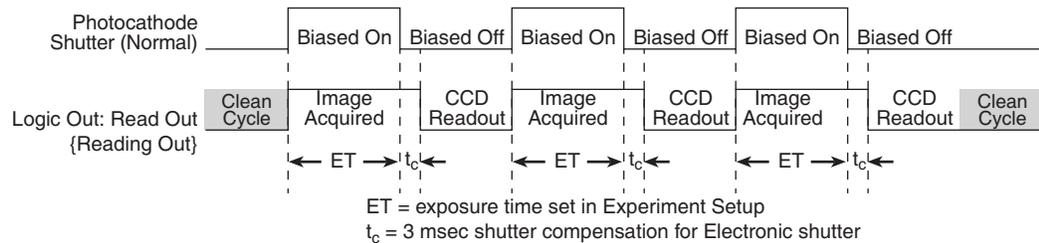
4411-0137_0022

The configuration of clean cycles is performed on the **Hardware Setup —> Cleans/Skips** tab {via the **Sensor Cleaning** pane accessed on the **Sensor** expander}. When you set up the camera for the first time, default values are automatically inserted into these fields. These will give the best results for most applications. Even so it is a good idea to know what these entries mean with regard to cleaning.

- **Number of Cleans {Number of Clean Cycles}** value is usually set to one (1.) These are additional clean cycles that can be required after a start exposure signal is received and the current clean cycle has finished. The maximum value for this entry depends on the camera.

- **Number of Strips per Clean {Clean Cycle Height}** sets the number of rows that will be shifted and discarded per clean cycle. While a large number such as the number of rows in the array may result in the best cleaning of the array, the trade off is that there may be a significant delay between the receipt of a start exposure signal and the beginning of the actual exposure. This delay occurs because the current clean cycle must be completed before a start exposure signal received during the cycle will be implemented. Typically, the default setting is much smaller and in time critical experiments, the setting should be 1 or 2.

- **Continuous Cleans {Clean Until Trigger}** is available when the start of exposure is tied to an external trigger. In WinX, this cleaning becomes active when **External Sync** timing mode is selected. In LightField, it becomes active when **Trigger Response** is set to **Readout Per Trigger** or **Shift Per Trigger**.

- **Skip Serial Register Clean** (deselected) **{Clean Serial Register}** The Top margin inactive parallel strips on a CCD are made up of the dark pixels that come before the active strips on a sensor as they exit to the serial register. When these are available (i.e., Pre Dummies {Top Margin} > 0,) they serve the purpose of cleaning the serial register before readout of the active strips. In LightField, if there are no inactive parallel strips (i.e., {Top Margin} = 0,) selecting **Clean Serial Register** forces a clean of the serial register before readout of the active strips.

> **NOTE:**
>
> The start of the exposure is signaled by the **Read Out** {**Reading Out**} output of the **LOGIC OUT** connector going low but will not occur until the current clean cycle and the additional user-defined number of cleans (typically 0) have finished. "Number of Cleans" is defined on the **Setup —> Hardware —> Cleans/Skips** tab {**Sensor Cleaning** fly-out pane on **Sensor** expander}. If you enter a value other than "0", you will further delay the start of the exposure by that number of clean cycles.

5.4   Phosphor Decay Delay

The WinX and LightField applications allow a delay between the end of the exposure time and the beginning of the array readout to be specified. This time is inserted to allow the phosphor to decay to 1% before readout occurs and will vary depending on the phosphor type. This delay has no effect on the actual time it takes for the phosphor to decay.

> **NOTE:**
>
> In the case of an experiment using a PI-MAX4:1024i and a very short exposure time, artifacts will appear in the first frame unless the phosphor decay delay is set to 3 ms. This amount of delay will ensure that the vertical registers (under the mask) are cleared before the acquired signal is shifted under the mask.

Figure 5-3 and Figure 5-4 show the dialogs on which the custom decay delay time is configured.

Figure 5-3:   WinX: Phosphor Decay Delay

ENTER PHOSPHOR
DECAY DELAY TIME
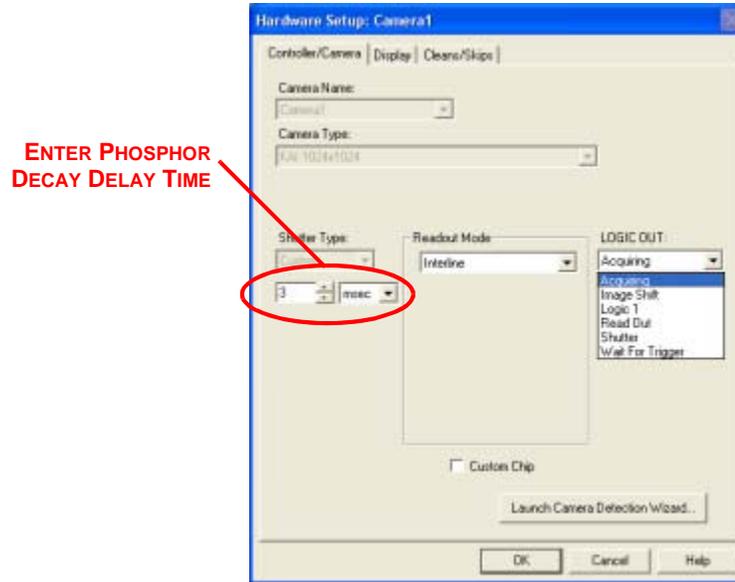
4411-0137_0023

Figure 5-4:   LightField: Phosphor Decay Delay Parameters
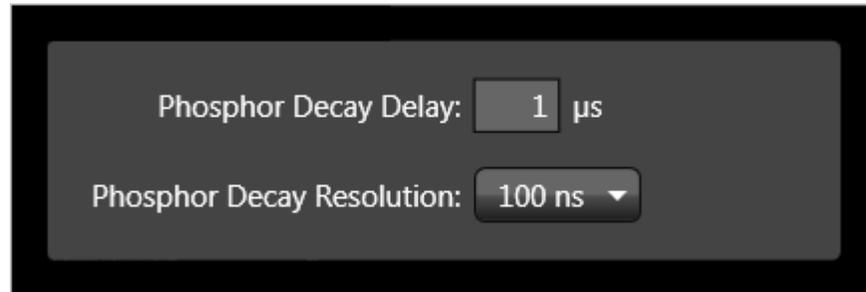
4411-0137_0024

5.5   Temperature Control

WARNING!

Under normal conditions, the front end of the camera is sealed and backfilled so there is no danger of damage due to condensation.

5.5.1   Cooling Method

Cooling the CCD array reduces the amount of dark charge, thereby acting to improve the signal-to-noise ratio. An internal Peltier device directly cools the cold finger on which the CCD is mounted. The heat produced by the Peltier device is then removed by the air drawn into the camera by the internal fans and exhausted through the side-panel grill. The fans are always running and cooling the CCD and the internal electronics. Additional heat removal can be performed by circulating coolant through an internal heat block.

- Air-cooling
  With air-cooling alone, at an ambient temperature of 25°C, temperature lock at -25° should typically take ten to twenty minutes. Cooling performance is affected by the CCD array being used (i.e., larger arrays may take longer to cool than smaller arrays.) Also, if the lab is particularly warm, achieving temperature lock might take longer or not be obtainable at all.
- Supplemental Circulating Coolant

Allows temperature lock to be achieved more rapidly than would be required to lock at the same temperature with air-cooling alone. In addition, it will be possible to achieve temperature lock at lower temperatures, typically 10-15 degrees lower than would be possible with air-cooling alone. Use the Princeton Instruments CoolCUBE$_{II}$ coolant circulator. It is a closed circulation system that depends on ambient air-cooling of the circulating coolant. With the CoolCUBE$_{II}$, even if the laboratory has high humidity (as long as it is non-condensing,) there will be no condensation. Refer to for CoolCUBE$_{II}$ setup instructions.

5.5.2   Necessary Cooling Precautions

Cooling performance can be enhanced by circulating water with a temperature below laboratory ambient but **this will increase the risk of condensation inside the PI-MAX4**. Condensation can cause **catastrophic failure** of camera electronics. Any resulting damage would be considered to have resulted from improper operation and will **not** be covered by the Warranty. **Even ordinary tap water is too cold to be used without risk!** For safety, water should be no colder than the ambient temperature. Closed circulation systems that depend on ambient air-cooling of the circulating water will generally give good results. If water colder than the laboratory ambient temperature must be used, it is absolutely essential that the PI-MAX4 be operated where the humidity is low enough to prevent internal condensation. If the coolant is below the freezing temperature of water, use a mixture of 50% water and 50% ethylene glycol as the coolant.

The easiest and most practical way to achieve the required low humidity is to put the PI-MAX4 inside a closed container and purge the container with a continuous flow of dry air. The air must be dry enough to have a dew point lower than the coolant temperature. On completion of the experiment, be sure to continue the purge until the PI-MAX4's internal cold surfaces have had time to warm to the ambient laboratory temperature. Contact the factory if you require additional information.

5.5.3   Setting the Temperature

Regardless of the type of cooling, the CCD array temperature is set via the application software. When WinX is the controlling software, temperature control is done via **Setup —> Detector Temperature** menu choice. When Light Field is being used, temperature control is done on the **Sensor** expander.

Once the desired **Target Temperature** {**Temperature Setpoint**} has been set, the software controls the camera's cooling circuits to reach set array temperature. On reaching that temperature, the control loop locks to that temperature for stable and reproducible performance. When the **Target Temperature** {**Temperature Setpoint**} has been reached, the current temperature is **Locked**. The on-screen indication allows easy verification of temperature lock.

Temperature lock to a set temperature in the operating range will typically occur within ten minutes. Another five minutes will be required to reach maximum temperature stability.

NOTE:

The WinX **Detector Temperature** dialog will not display temperature information while you are acquiring data.

5.6   Exposure

Data acquisition has two parts: exposure and readout. Exposure refers to the integration of a signal of interest on the CCD array and readout is the transfer of the integrated signal from the array pixels to a shift register and from there to a preamplifier. During exposure, each pixel in the two-dimensional grid of individual pixels senses the intensity of light falling on its collection area and stores a proportional amount of charge in its associated well. Once charge accumulates for the exposure time (via gating sequences defined in the application software,) the pixels are read out serially.

CCD arrays are always sensitive to light. Therefore, with very few exception, light must not be allowed to fall on the array during readout. Intensified cameras such as the PI-MAX4 rely on gating the intensifier off to prevent light from reaching the array. During each data acquisition, the intensifier is gated on and off (this may happen a number of times if there are multiple gates per exposure) to allow the pixels to register light during the "on" period. It is gated off for the readout period.

5.6.1   Exposure with an Image Intensifier

PI-MAX4 cameras use an image intensifier both to gate light on and off and to greatly increase the brightness of the image. In these cameras the image intensifier detects and amplifies the light, and the CCD is used for readout. The exposure programmed by software in this case refers to duration of gating of the intensifier.

The intensifier's Micro-Channel Plate (MCP) is composed of more than 106 individual miniature electron multipliers with excellent input-to-output spatial geometric accuracy. Intensifier gain is varied by adjusting the voltage across the MCP or the voltage across the MCP output and the phosphor. This second parameter is a factory adjustment as it affects both the gain and the resolution of the intensifier.

Detection of extremely weak Continuous Wave (CW) signals (e.g., luminescence, Raman scattering from solid state samples,) is typically limited by the dark current of the intensifier's photocathode, typically referred to as the Equivalent Background Illumination (EBI.)

5.6.1.1   Exposure Timing

Exposure is controlled by the gate width setting and the number of gates per frame. The total exposure time is the product of gate width and number of gates per frame. The time of the opening of the gate is controlled by the delay (i.e., time from trigger to optical opening.) This is set in WinX or LF. Refer to Chapter 4, First Light, on page 47.

The **MONITOR** output may be used with an oscilloscope to determine when the intensifier is being gated on. The relationship between **MONITOR** and optical gate varies depending the specified gating mode.

- **Picosecond Gating**
  When using picosecond gating, the start of the **MONITOR** pulse coincides with the opening of the intensifier, but the width of the **MONITOR** pulse is unrelated to the total intensifier ON time.

- **Fast Gate Tubes**
  When using Fast Gate Tube and the programmed gate width is < 10 ns, the width of the **MONITOR** pulse is approximately 2 ns wider than the intensifier ON time.

- **Slow Gate Tubes**
  When using Slow Gate Tube the width of the **MONITOR** pulse is approximately the same as the timing of the electrical gate drive to the intensifier. However, because of the slow gate nature of the intensifier, the optical gate will be delayed and distorted relative to the **MONITOR** pulse. The error is related to the slowness of the individual slow-gate intensifier tube. Typical deviations are 50 -100 ns.

5.6.2   Saturation

When signal levels in some part of the image are very high, charge generated in one pixel may exceed the "well capacity" of the pixel, spilling over into adjacent pixels in a process called "blooming." If this is the case, you could reduce the intensifier gain or read out more frequently, with signal averaging to enhance S/N (Signal-to-Noise ratio) accomplished through the software.

⚠ **CAUTION!** ——————————————————————

Signals that are large enough to bloom may damage the intensifier.

For signal levels low enough to be readout-noise limited, longer exposures, and therefore longer signal accumulation in the CCD, will improve the S/N ratio approximately linearly with the length of exposure time. There is, however, a maximum time limit for on-chip averaging, determined by either the saturation of the CCD pixels by the signal or the loss of dynamic range due to the buildup of dark charge in the pixels.

5.7   Background Subtraction

Each CCD has its own dark charge pattern or background that can be subtracted from the total acquired signal. By subtracting this background, you can eliminate the dark charge, which might otherwise hide low-intensity signal.

When setting up for background subtraction, set up the experiment conditions for acquiring the actual image (i.e., camera temperature, gating sequences, region of interest, timing mode, etc.,) and then, while blocking the incoming signal from the array, acquire a dark charge background image under those conditions. Once the background image is acquired, save it to disk.

After storing the background data to disk, you have two choices for background subtraction: automatic or post-processing.

- **Automatic**
  In WinX, this approach requires that you activate "Background" and specify the background filename on the **Acquisition —> Experiment Setup… —> Data Corrections** tab before acquiring an image. In LightField, you must check the **Apply Background Subtraction** box on the **Online Corrections** expander and select the appropriate background file or acquire a new background. When you acquire an image, the specified background will be subtracted automatically from the raw image data before the corrected data is displayed and is available for storage to disk.

- **Post-Processing**
  If you prefer to acquire and preserve the raw image data, make sure that "Background" is not active on the **Acquisition —> Experiment Setup… —> Data Corrections** tab {**Apply Background Subtraction** box is not checked}. Then, acquire the image, save the raw image data to disk. In WinX you would then use the Image (or Spectra) Math function (accessed from the **Process** menu) to subtract a background data file from the raw image data: the resulting data can then be saved to disk in a separate file. In LightField you would open the data in the **Data Workspace**, select **Background…** from the **Processes** drop-down list, choose the appropriate background file, click on **Preview**, and then click on **OK**. You can now click on the **Save** button, edit the filename if desired, and save the data to disk.

5.8   Readout of the Array

At the end of the exposure, the charge from the pixels is shifted to the shift register, amplified, and digitized. Depending on the experiment design, binning may also occur as part of the readout operation.

- For the PI-MAX4:1024i camera and WinX, dual port readout mode is selected whenever full image readout is selected or when the region of interest (ROI) is defined to be horizontally symmetrical and centered. Single port readout is activated when the ROI is not horizontally symmetrical and centered. The same rules apply whether or not binning is utilized. Readout in single port mode may be slower than dual port mode readout. The port used for single port mode is dictated by the CCD design.

- For the PI-MAX4:1024i camera and LightField, when 2 port readout is selected, you can acquire either a full image or a region of interest (ROI) defined to be horizontally symmetrical and centered. If the ROI is not horizontally symmetrical and centered, single port readout must be selected. The same rules apply whether or not binning is utilized. Readout in single port mode may be slower than dual port mode readout. The port used for single port mode is dictated by the CCD design.

- For the PI-MAX:1024x256, the signal is read out of a single port.

5.8.1   Interline CCD Readout

In this section, a simple 6 x 3 pixel interline CCD, shown in Figure 5-5, is used to demonstrate how charge is shifted and digitized using a single port.

Figure 5-5:   **Interline CCD Readout**
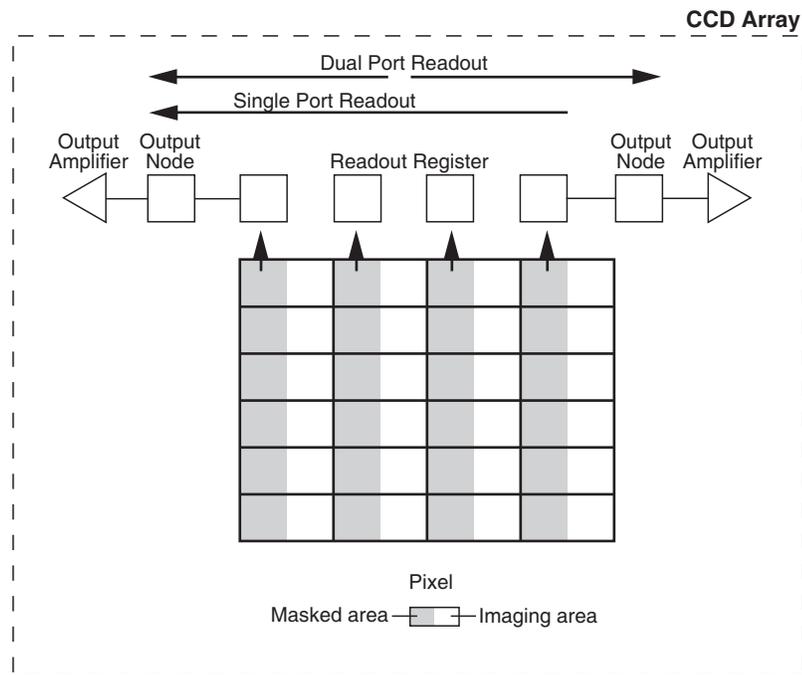
Two methods of operation, exposure, and readout may occur:

- **Overlapped**
  In overlapped operation, each exposure begins while the readout of the previous exposure is still in progress.

- **Non-Overlapped**
  In non-overlapped operation, each readout is completed before the next exposure begins. Non-overlapped operation is automatically selected when the configured exposure time is shorter than the required readout time.

This process has been divided into four steps:

1. Figure 5-6 illustrates the array early in the exposure cycle. The imaging areas contain charge proportional to the amount of light integrated on each of them. The masked (storage) areas are empty because no charge has been transferred to them. The arrows between adjacent imaging and masked areas indicate the direction the charge will be shifted when the transfer occurs.

Figure 5-6:   Step 1: Non-Overlapped, Early Exposure

1 Empty Readout Register. Exposure has ended and image is being transferred to masked areas.
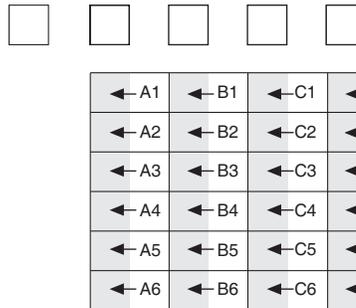
2. Figure 5-7 shows the situation early in the readout cycle. The charge in the imaging areas has been transferred to the adjacent masked areas and up-shifting to the readout register has started. Note that a second exposure does not begin while the readout is in progress because the intensifier is not gated on at this time.

Figure 5-7:   Step 2: Non-Overlapped, Early Readout

2 Image has been shifted to masked areas and first line has been shifted to Readout Register.
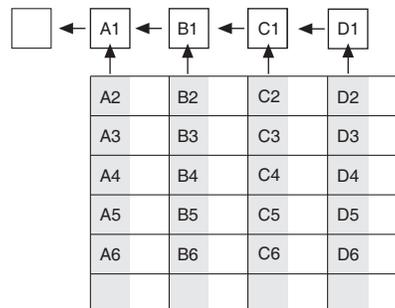
3. Figure 5-8 shows the transfer to the output node. The lowermost pixel in each column is shown empty. Each row of charges is moved in turn into the readout register, and from there to the output node and off of the array for further processing. The process continues until all charges have been completely transferred out of the array. The image intensifier is off during this time so no signal charge is accumulated, but dark current does accumulate. Because this scheme is less time efficient than that used in the overlapped mode, the frame rate may be lower in non-overlapped operation than it is in overlapped operation with the some gating setups.

Figure 5-8: Step 3: Non-Overlapped, Transfer to Output Node

3 Charge from first pixel has been
shifted to the Output Node.

A1	B1	C1	D1	
A2	B2	C2	D2	
A3	B3	C3	D3	
A4	B4	C4	D4	
A5	B5	C5	D5	
A6	B6	C6	D6	
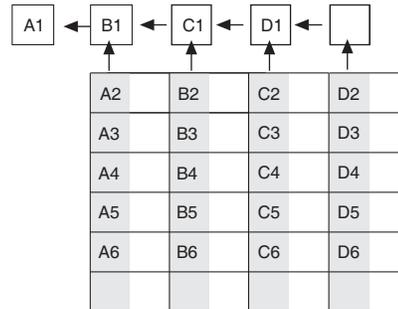
4411-0137_0028

4. Figure 5-9 illustrates the end of the readout. Both the imaging and storage areas are empty. When the intensifier is gated on again, signal charge will again be accumulated.

Figure 5-9: Step 4: Non-Overlapped, End of Readout

4 After first image is read out, masked areas
are empty. Second exposure begins if in Freerun
mode. Otherwise, waits for Ext Sync.
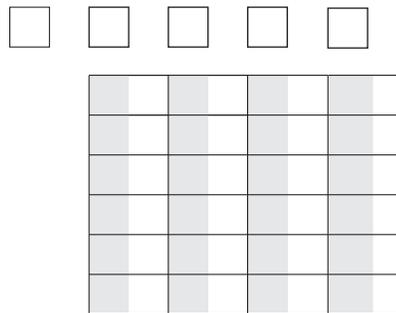
4411-0137_0029

🔍 **NOTE:** ─────────────────

A subsection of the CCD can be read out at full resolution, sometimes increasing the readout rate while retaining the highest resolution in the region of interest (ROI.)

5.8.2 Full-Frame CCD Readout

The following PI-MAX4 cameras use a full-frame architecture CCDs for data acquisition:

- PI-MAX4: 1024f;
- PI-MAX4: 2048f;
- PI-MAX4:1024x256.

Figure 5-10 illustrates the various stages of this process. **Step 1** in Figure 5-10 represents a CCD immediately after exposure but before the beginning of readout. The capital letters represent different amounts of charge, including both signal and dark charge. This section describes readout at full resolution, where every pixel is digitized individually.

Figure 5-10: Full Frame CCD Readout
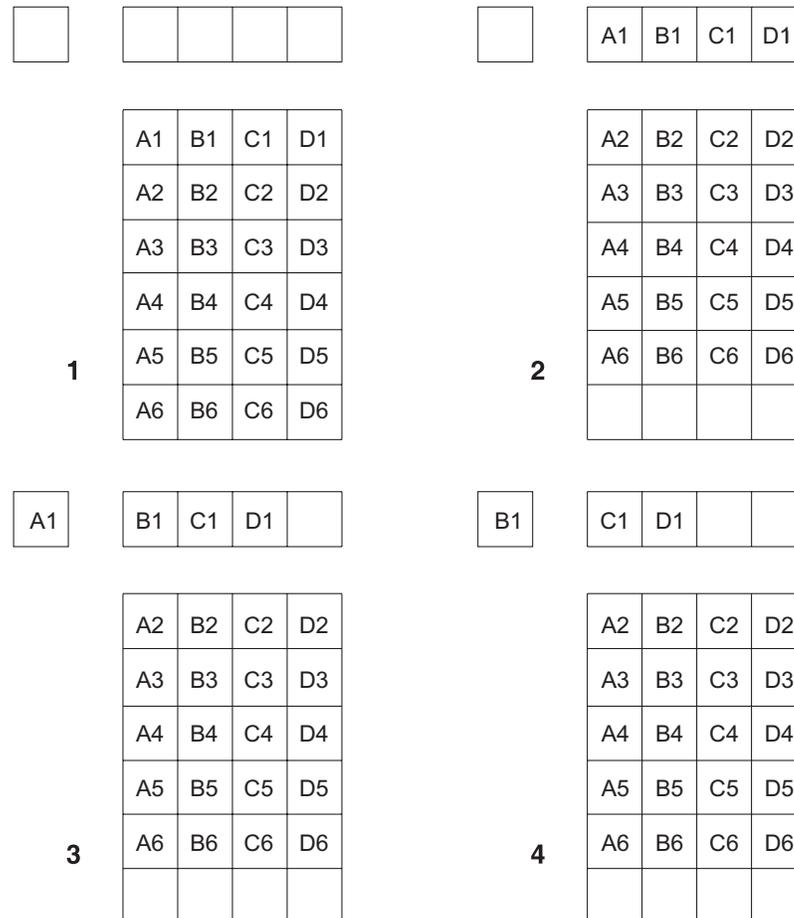
4411-0137_0030

Readout of the CCD begins with the simultaneous shifting of all pixels one row toward the "shift register," in this case the row along the top. The shift register is a single line of pixels along the edge of the CCD, not sensitive to light and used for readout only. Typically the shift register pixels hold twice as much charge as the pixels in the imaging area of the CCD.

After the first row is moved into the shift register, the charge now in the shift register is shifted toward the output node, located at one end of the shift register. As each value is "emptied" into this node it is digitized. Only after all pixels in the first row are digitized is the second row moved into the shift register. The order of shifting in this example is therefore A1, B1, C1, D1, A2, B2, C2, D2, A3, ….

After the accumulated charge has been shifted out of each pixel, the remaining charge is zero, meaning that the array is immediately ready for the next exposure.

The equations that determine the rate at which the CCD can be read are described below.

The time required to capture a full frame at full resolution is defined by:

(1) $$t_R + t_{exp} + t_c$$

where:

- t_R is the CCD readout time;
- t_{exp} is the exposure time;
- t_c is the phosphor decay time.

The readout time is approximately given by:

(2) $$t_R = [N_x \bullet N_y(t_{sr} + t_v)] + (N_x \bullet t_i)$$

where:

- N_x is the smaller dimension of the CCD;
- N_y is the larger dimension of the CCD;
- t_{sr} is the time needed to shift one pixel out of the shift register;
- t_v is the time needed to digitize a pixel;
- t_i is the time needed to shift one line into the shift register.

A subsection of the CCD (number of horizontal pixels must be divisible by 4) can be read out at full resolution, sometimes dramatically increasing the readout rate while retaining the highest resolution in the region of interest (ROI.) To approximate the readout rate of an ROI, in Equation 2 substitute the x and y dimensions of the ROI in place of the dimensions of the full CCD. Some overhead time, however, is required to read out and discard the unwanted pixels.

5.8.3 Binned Readout (Hardware Binning)

Binning is the process of adding the charge from adjacent pixels together to form a single pixel (sometimes called a super-pixel,) and it can be accomplished in either hardware or software. Rectangular groups of pixels of any size may be binned together, subject to some hardware and software limitations.

Hardware binning reduces readout time and the burden on computer memory by summing charge **before** the preamplifier reads out the signal. For signal levels that are readout noise limited this method improves S/N ratio linearly with the number of pixels grouped together. For signals large enough to render the camera photon shot noise limited, the S/N ratio improvement is roughly proportional to the square-root of the number of pixels binned. In the WinX application, hardware binning is set up on the **Acquisition —> Experiment Setup… —> ROI Setup** tab by entering a value in the **Group** fields: for example, a "2" in each of the Group fields will set up 2 x 2 hardware binning. In LightField, hardware binning is set up via the **Region of Interest** expander, first by verifying that hardware binning is selected on the **Advanced** fly-out pane, then selecting **Full Sensor Binned**, and entering a "2" in fields or by clicking on the **Edit ROIs…** button and creating a custom ROI with **Bin W** and the **Bin H** values of "2".

Limitations of hardware binning include:

- Lowered resolution because charge from adjacent pixels is summed into a super pixel.
- Increased possibility to blooming. Because shift register pixels typically hold only twice as much charge as image pixels, the binning of large sections may result in saturation and spilling of charge back into the image area
- Possible data loss if the total charge binned together exceeds the capacity of the shift register or output node.
- For dual port operation, there are symmetry requirements that limit the choice of patterns. Regions of interest (ROIs) must be symmetrical about the center line (horizontal.)
- The number of pixels in the serial (horizontal) direction must be evenly divisible by 4, even after binning.

The possibility of blooming or data loss strongly limits the number of pixels that may be binned in cases where there is a small signal superimposed on a large background, such as signals with a large fluorescence. Ideally, one would like to bin many pixels to increase the S/N ratio of the weak peaks but this cannot be done because the fluorescence would quickly saturate the CCD. The solution is to perform the binning in software. Limited hardware binning may be used when reading out the CCD. Additional post-processing binning is accomplished in software, producing a result that represents many more photons than was possible using hardware binning.

5.8.3.1 CCD Type and Readout Port(s)

PI-MAX4 cameras are equipped with either a full frame, frame transfer, or interline CCD. Depending on the specific CCD architecture used, single or dual/single port readout is supported.

> **REFERENCES:**
>
> For PI-MAX4 model-specific information and specifications, refer to Table A-3 in Appendix A, Technical Specifications, on page 256.

> **NOTE:**
>
> For CCDs that support both dual and single port readout, when single port readout is active, the hardware port that is to be used has been factory-configured and cannot be changed.

Dual port readout is approximately two times faster than single port readout and occurs whenever the full frame is being read out or when an ROI is symmetrical about the horizontal center of the CCD. In WinX, single port readout automatically occurs when an ROI is not symmetrical about the horizontal center of the CCD. In LightField, single port readout can be selected via the **Analog to Digital Conversion** expander.

Full Frame Binning

Figure 5-11 shows an example of 2 x 2 binning with dual port operation for an interline array. Each pixel of the image displayed by the software represents 4 pixels of the array.

Figure 5-11: Dual Port Readout: 2 × 2 Binning of Interline CCD
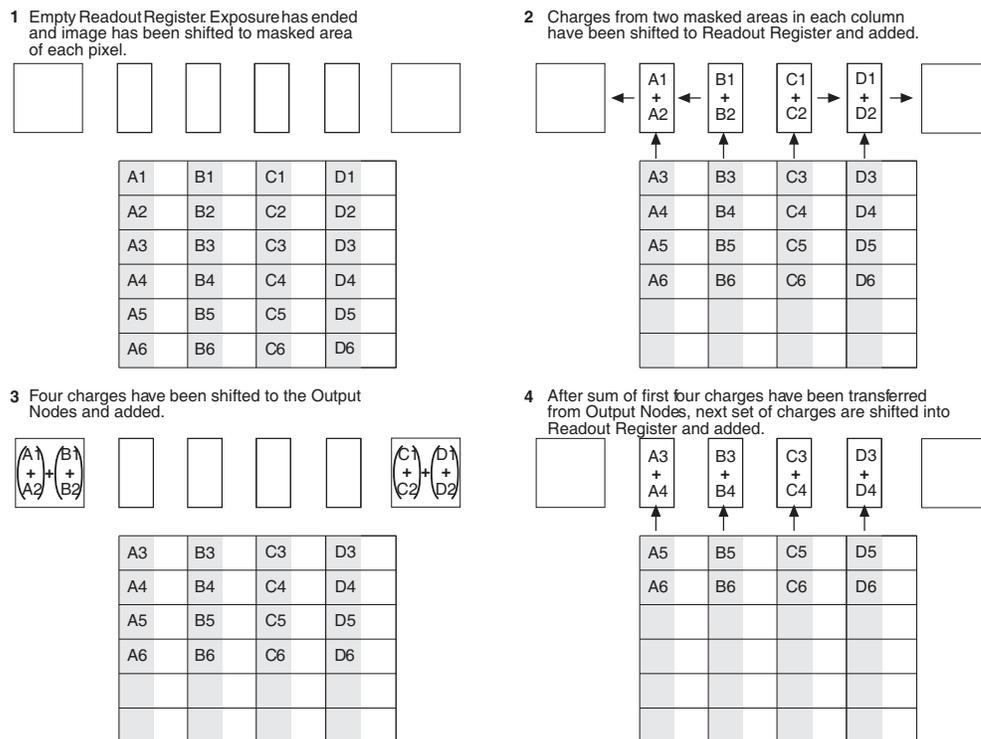
4411-0137_0031

Figure 5-12 shows the LightField **Region of Interest** expander for full sensor 2 x2 binning.

Figure 5-12: Dual Port Readout: LightField Setting, 2x2 Binning, Interline CCD
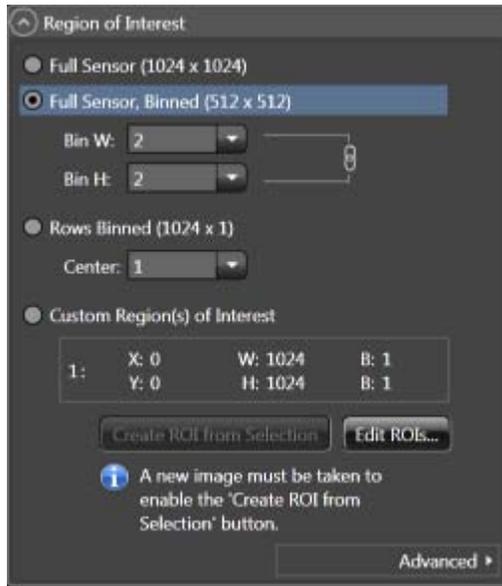
4411-0137_0032

Figure 5-13 shows an example of single port operation for a full frame array.

Figure 5-13: Single Port Readout: 2 × 2 Binning of Full Frame CCD
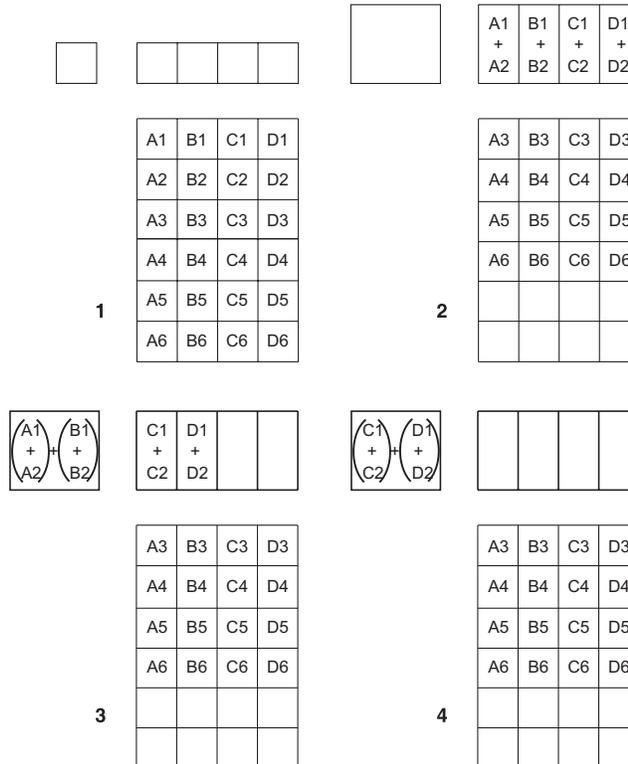
4411-0137_0033

WinX and Partial Frame ROI Binning

Regardless of the type of array (i.e., full-frame or interline,) when setting up a partial frame ROI, keep in mind that for the PI-MAX4 **the number of pixels in the serial (horizontal) direction must be evenly divisible by 4, even after binning**.

> **NOTE:**
>
> Depending on the specific software application, the horizontal axis may be referred to as either **X** or **Wavelength**.

The following examples include partial frame ROIs both with and without binning. The terminology is based on the **ROI Setup** tab illustrated in Figure 5-14.

- **X Start to End** = 200 pixels, no grouping (binning.) Since 200/4=50, this is a valid ROI setup.
- **X Start to End** = 200 pixels and grouping (binning) is by 8. The resulting number of super pixels is 25. Since 25/4=6.25, this is not a valid ROI setting for the horizontal direction.
- **X Start to End** = 240 pixels, no grouping (binning.) Since 240/4=60 this is a valid ROI setup.
- **X Start to End** = 240 pixels and grouping (binning) is by 3. The resulting number of super pixels is 80. Since 80/4=20, this is a valid ROI setup.
- **X Start to End** = 240 pixels and grouping (binning) is by 16. The resulting number of super pixels is 15. Since 15/4=3.75, this is not a valid ROI setting for the horizontal direction.

Figure 5-14: Experiment Setup: ROI Configuration Dialog

NOTE THAT A VALUE OF **8** IS NOT VALID FOR AN **X** START-END OF 200.

4411-0137_0034
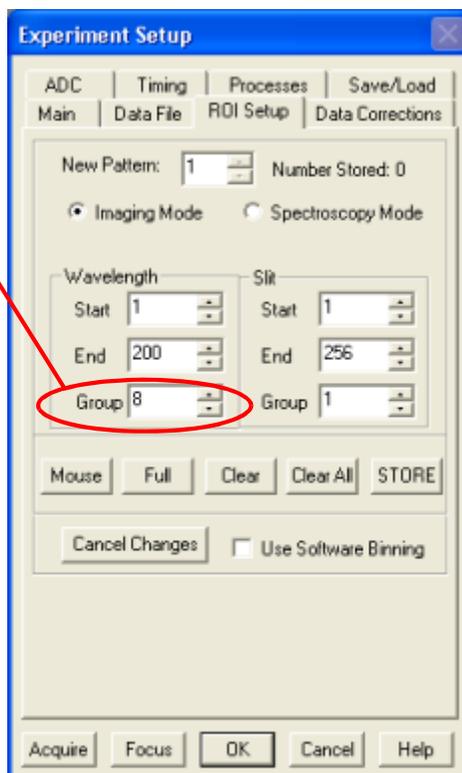
5.8.3.2   *LightField and Partial Frame ROI Binning*

Partial Frame ROI binning can be defined via the **Region of Interest** expander's **Custom Region(s) of Interest** function and the **Edit Regions of Interest** window similar to that shown in Figure 5-15.

Figure 5-15: Typical Edit Regions of Interest Window
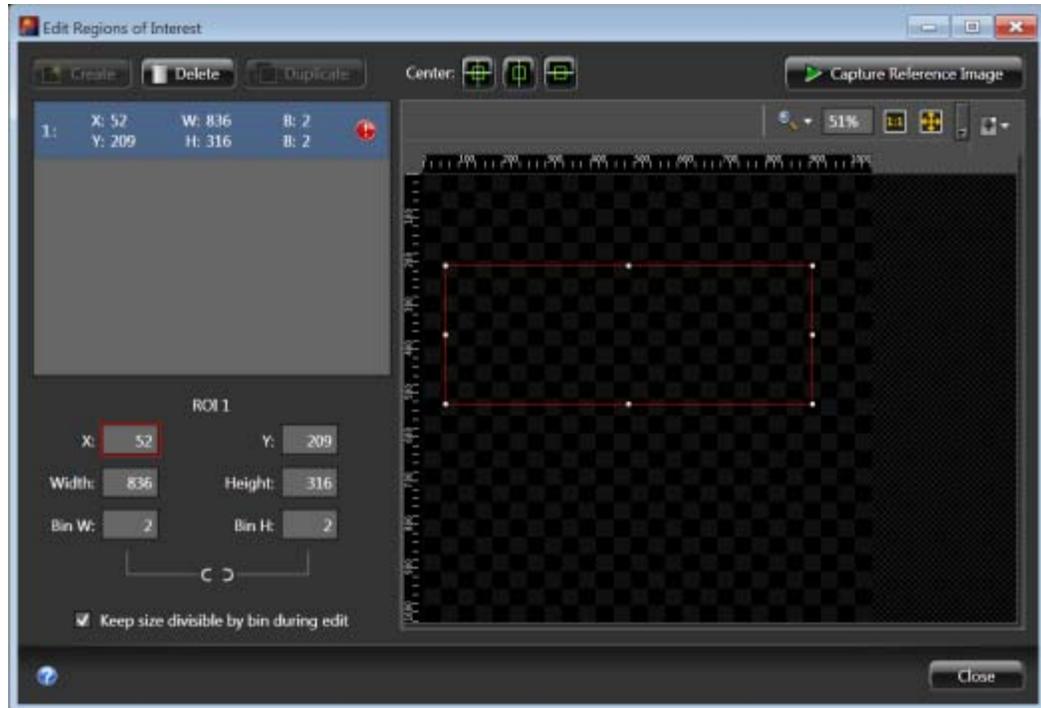
4411-0137_0035

The ROI illustrated has been created for a PI-MAX4:1024i using dual port readout. Because the ROI is not centered horizontally, an **Experiment Conflict** is shown. Left-clicking on the

![icon] icon displays a pop-up window in which detailed information about the conflict is provided. In this instance, the ROI needs to be centered horizontally.

To center the ROI, left-click on the ![icon] icon near the top of the window to reposition the ROI correctly.

> **NOTE:**
>
> Only one ROI may be created when Dual Port readout has been selected.
>
> When Single Port readout is active (i.e., the CCD is a 1024 x 256, or Single Port has been selected with a 1024 x 1024 interline CCD,) multiple ROIs may be created and horizontal centering is not required. See Figure 5-16.

Figure 5-16: Single Port Readout: Partial Frame, 2×2 Binning, Interline CCD
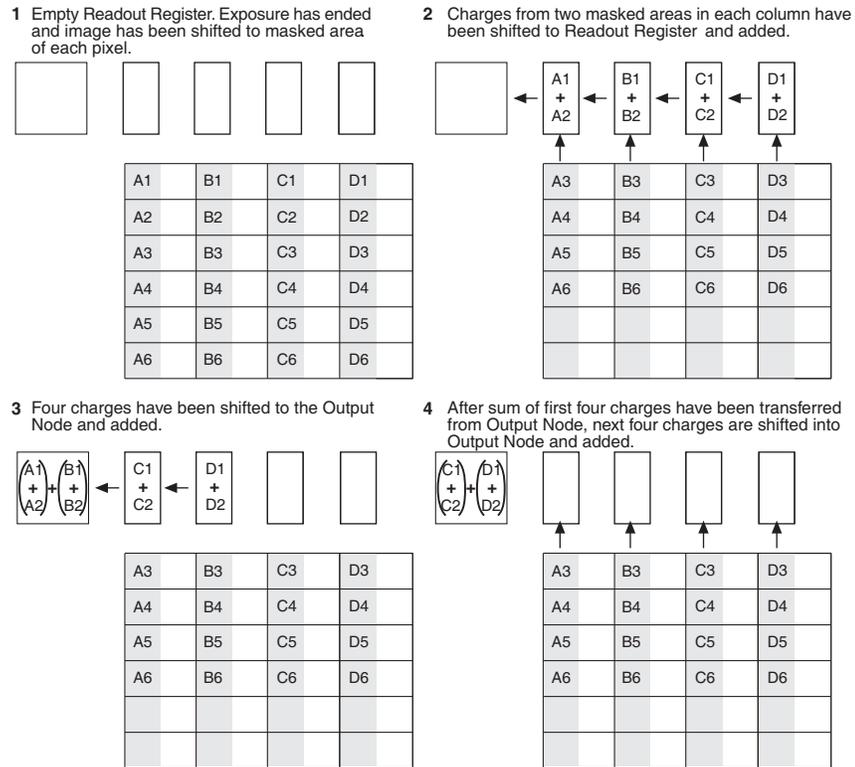
4411-0137_0036

Figure 5-17 shows the LightField **Region of Interest** expander and 5 x 3 binning setup for an interline sensor with dual port readout selected. Both the **Full Sensor, Binned** and the **Custom Region(s) of Interest** results of using the 5 and 3 bin values are reported.

📖 **NOTE:**

> On LightField's **Region of Interest** expander, you can select **Full Sensor, Binned** and enter Bin W and Bin H values that would not be allowed if you selected **Custom Region(s) Interest** and entered them in the **Edit Regions of Interest** window. For example a Bin W=5 and a Bin H=3 would not be allowed via the **Edit Regions of Interest** window until you created a horizontally centered ROI whose dimensions would permit even division by those values. If you use the **Full Sensor, Binned** function, LightField creates the appropriately sized ROI and reports the resulting image size. The **Custom Region(s) of Interest** panel shows the non-binned ROI size and the bin values that will be applied to it.

Figure 5-17: Dual Port Readout: LightField Settings, 5×3 Binning, Interline CCD

4411-0137_0037

5.9   Software Binning

Software binning is a software-averaging post-acquisition process that can be performed on either non-binned or hardware-binned data. This type of binning can improve the S/N ratio by as much as the square root of the number of binned pixels. Unfortunately, with a high number of scans (i.e., above 100,) camera 1/f noise may reduce the actual S/N ratio to slightly below this theoretical value. Also, if the light source used is photon flicker (1/f noise) limited rather than photon shot-noise limited, this theoretical signal improvement cannot be fully realized. Again, background subtraction from the raw data is necessary.

Software binning is also useful in high light level experiments, where the camera is again photon shot-noise limited. Summing multiple pixels in software corresponds to collecting more photons, and results in a better S/N ratio in the measurement.

In LightField and WinX software, software binning can be configured to occur automatically or as a manual post-processing operation.

- **LightField**
  Automatic software binning is configured by entering the **Bin W** and **Bin H** parameters directly on the **Region of Interest** expander or when creating a Custom ROI via the **Edit Regions of Interest** window. Alternatively you can acquire raw data, load the file in the Data Workspace, select **Software Binning** from the **Processes** menu, enter the binning parameters, preview the resulting data, **OK** the process, and then use the Data Workspace **Save** function to save the result to an appropriately named file.

- **WinX**
  Automatic software binning is configured by entering **Group** parameters on the **Acquisition —> Experiment Setup… —> ROI Setup** tab card and then selecting the **Use Software Binning** check box. The drawback to automatic binning is that the raw data is lost. Alternatively, raw data can be acquired and then the post-processing binning function (located on the **Process —> Binning and Skipping…** dialog) used to select the input data, enter the binning parameters, and save the result to an appropriately named file.

5.10   Controller Gain {Analog Gain}

Controller gain, a function of the preamplifier, is software-selectable and is used to change the relationship between the number of electrons acquired on the CCD and the Analog-to-Digital Units (ADUs or counts) generated. Selecting the level of gain is done on the **Acquisition —> Experiment Setup… —> ADC** tab {**Analog to Digital Conversion** expander}. Available options are:

- **1 {Low}**
  Users who measure high-level signals may wish to select **1{Low}** for digitization of larger signals: more electrons are required per ADU. Since binning combines the signal from two or more pixels, the user may also want to select **1 {Low}** if binning is being applied. In both instances, the goal is to prevent CCD saturation and maximize signal acquisition.

- **2 {High}**
  Users who consistently measure low-level signals may wish to select **2 {High}**, which requires fewer electrons to generate an ADU and reduces some sources of noise. If saturation occurs at this setting, **1 {Low}** should be selected.

The following three factors should be considered in order to make an appropriate gain selection:

- The intensity of the incoming signal;
- Binning;
- CCD saturation.

5.11   Digitization

During readout, an analog signal representing the charge of each pixel (or binned group of pixels) is digitized. The number of bits per pixel is 16.

Some PI-MAX4 cameras are equipped with two complete analog channels, including separate A/D converters. Because the readout noise of CCD arrays increases with the readout rate, it is sometimes necessary to trade off readout speed for high dynamic range. The two analog converters, both high speed, are optimized for slower read rates by digitally processing the signal in the camera before transferring it to the host.

5.12   Logic Out Control

The TTL-compatible logic level output (0 to +3.3 V) from the **LOGIC OUT** connector on the rear panel can be used to monitor camera status and control external devices. By default, the logic output level is high while the action is occurring. The timing of the level changes depends on the output type selected on the **Setup —> Hardware —> Controller/ Camera** tab {**Trigger** expander}. See Figure 5-18.

Figure 5-18: Typical PI-MAX4 Hardware Setup Dialog
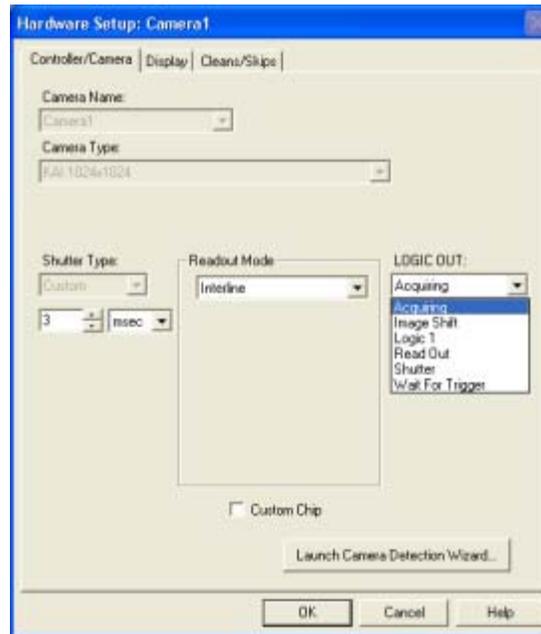
4411-0137_0038

Valid configuration settings for LOGIC OUT are:

- Acquiring {Acquiring}
  After a start acquisition command, this output changes state on completion of the array cleaning cycles that precede the first exposure. Initially low, it goes high to mark the beginning of the first exposure. In Focus mode operation it remains high until the system is halted. If a specific number of frames have been programmed, it remains high until all have been taken and then returns low. Figure 5-19 assumes three frames have been programmed.

Figure 5-19: Timing Diagram: Shutter {Shutter Open}, Read Out {Reading Out}, Acquiring {Acquiring}
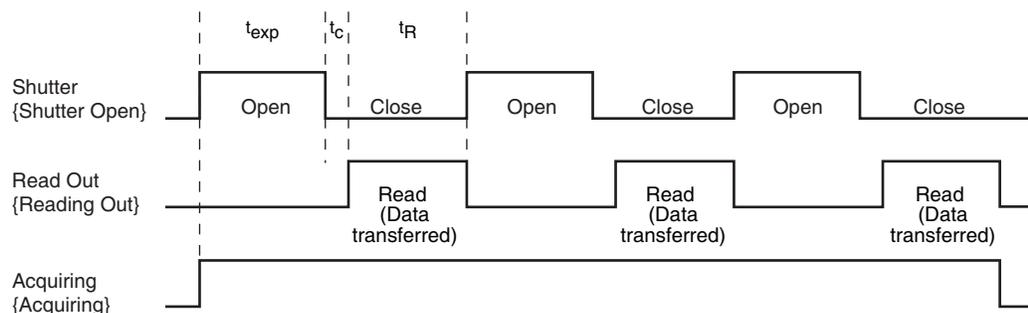
4411-0137_0039

- Image Shift {Shifting Under Mask}
  Driven high (logic 1) as a detected image is shifted under the mask.
  Specific signal timing is CCD-dependent as follows:
  — Interline CCD
    Driven high (logic 1) as the entire image is shifted under the CCD mask.
  — Full-Frame CCD
    Momentarily pulsed high (logic 1) as each line of the image is shifted.
  — Frame Transfer CCD
    Driven high (logic 1) for the duration of the image-area to storage-area transfer.
- Logic 1 {Always High}
  The level at the connector is high.
- Read Out {Reading Out}
  It is at a logic high when CCD is being read; otherwise low.
- Shutter {Shutter Open}
  This level is at a logic high when the photocathode is gated on (signal is accumulating on the CCD) and can be used to drive an external electro-mechanical shutter. Contact the factory for more information.
- Wait for Trigger {Waiting For Trigger}
  This level is at a logic high when the camera is ready to acquire and is waiting for an external trigger (through the EXT SYNC connector) before exposing the CCD. The level goes low when a trigger is detected: exposure begins. The Wait for Trigger (WFT) signal goes high immediately after readout or after pre-open (if it is active.) If continuous cleans is enabled, the camera will check for a trigger at the EXT SYNC connector before entering a continuous clean cycle. If none has occurred, a cleaning cycle is initiated and completed. Before the next cycle begins, the EXT SYNC connector is checked again, and exposure will start if a trigger has occurred.

When the **Invert LOGIC** {**Invert Output Signal**} check box is checked, the output is at a logic low when an action is occurring.

5.13   WinX Experiment Setup

This section provides information about configuring an experiment using the WinX application software.

5.13.1   Main Tab

Within WinX, experiment setup parameters are typically configured on the **Experiment Setup —> Main** tab. See Figure 5-20.

Figure 5-20: Typical Experiment Setup Dialog: Main Tab
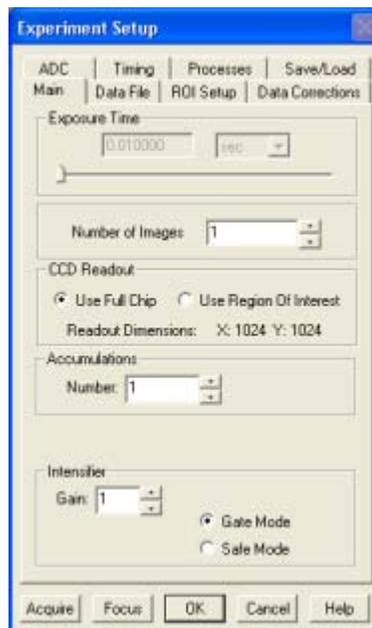
4411-0137_0013

These parameters configure such things as the number of separate frames (denoted as images or spectra) that will be acquired, how much of the CCD will be used to acquired data, the intensifier gain, and the intensifier mode. Each of the Main parameters are described briefly below.

- **Number of Images/Spectra and Accumulations**
  This is the number of sequential frames the software will collect and store in a single file. Each frame will be digitized and stored, but all of the frames will be in a single file. A frame may contain data from more than one region of interest as defined via the **ROI Setup** tab.

  If the **Accumulations** > 1, each stored frame will contain summed data sets from two or more exposures. The number of separate frames stored will the same as it would be for Accumulations =1, but the total number of exposures required would be the product of the **Number of Images/Spectra** parameter times the **Accumulations** value.

- **CCD Readout**
  This parameter determines whether the entire CCD array will be used to acquire a frame or if only a rectangular portion (or portions) of the array will be used. When **Use Region of Interest** is selected, data will be collected from the region(s) as defined on the **ROI Setup** tab. The full chip size or the sum of the active region(s) as defined on the ROI tab is displayed.

- **Intensifier Gain**
  The Intensifier gain setting provides continuous adjustment over a range of 1 to 100. Gain is approximately proportional to the number entered:
  — 100 corresponds to the maximum gain, or 100%;
  — 1 corresponds to approximately 1% of the maximum gain.
  The default value will provide good results in many applications. Gain can only be changed when acquisition is NOT occurring. In order to reconfigure the level of gain, acquisition must FIRST be stopped. The gain may then be changed/saved, and data acquisition may then resume. The suggestion is to start collecting data using a relatively low gain setting. If necessary, the gain may then be incrementally increased until optimal results have been obtained.

NOTE:

> The intensifier gain also affects the Equivalent Background Illumination (EBI) of the intensifier. One side result of this is that in order to properly perform background subtraction, a new background must be taken whenever the intensifier gain has been changed.

- **Intensifier Mode**
  The Intensifier Mode selection configures the bias control for the intensifier. Valid options are:
  — The intensifier is biased on/off by the specified pulser gate timing (Gate Mode);
  — The intensified is continuously biased off until Gate mode has been selected (i.e., Safe Mode.)

5.13.2 Timing Tab

Experiment setup requires the configuration of a variety of experiment timing parameters which are located on the **Experiment Setup —> Timing** tab. See Figure 5-21.

Figure 5-21: Typical Experiment Setup Dialog: Timing Tab

4411-0137_0040
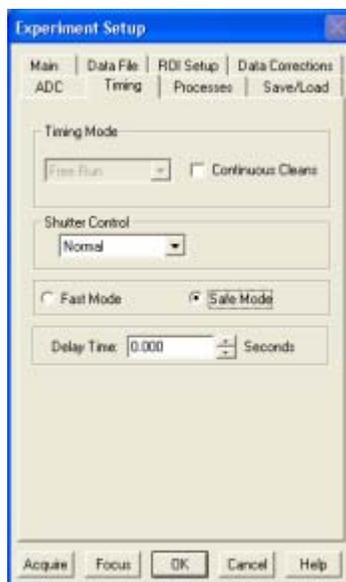
With the exception of Fast Mode/Safe Mode, which is described in full, the following paragraphs briefly describe these timing parameters. The settings appropriate to the intensifier mode and selected pulser are discussed in Chapter 6, LightField and Gated Operation.

- **Timing Mode**
  The timing mode parameter refers to the PI-MAX4's synchronization of data acquisition with an external TTL signal applied to the **Trigger In** connector on the back of the camera or an internal trigger generated by the internal timing generator. The modes available depend on the selected intensifier mode (**Safe** or **Gate**) and the selected pulser (**SuperSYNCHRO**.)

- **Fast Mode/Safe Mode**
  In WinX, the Fast Mode or Safe Mode selection determines whether the PI-MAX4 will run the experiment according to the experiment timing, with no interruptions from the computer, or the computer will interrupt the acquisition flow to process each frame as it is received. Figure 5-22 compares the two modes.

> **NOTE:** ——————————————————————
>
> The Safe Mode parameter found on the **Timing** tab is not the same as the **Intensifier** Safe Mode found on the **Main** tab.

Figure 5-22: Fast Mode/Slow Mode Flow Charts

4411-0137_0041
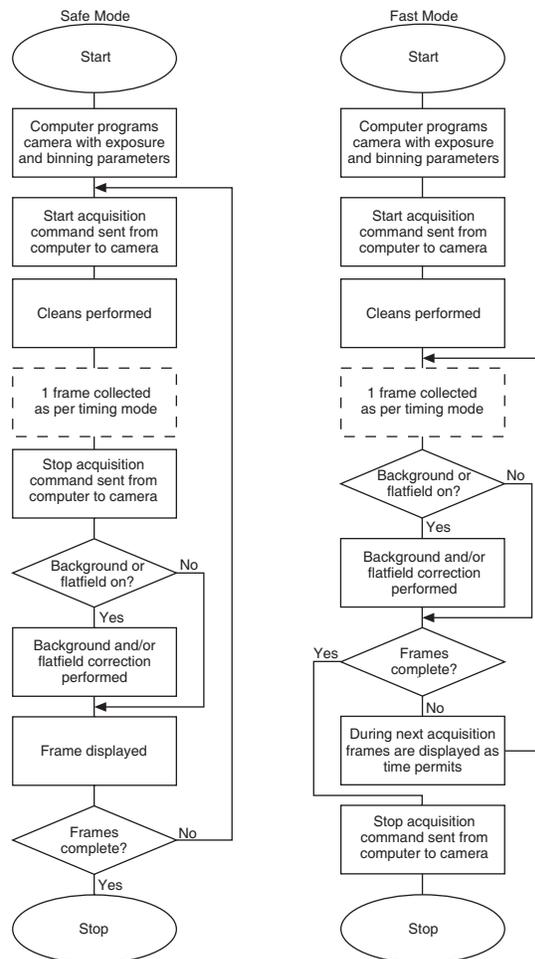
The two modes are described here:

— **Fast Mode**

Fast mode is primarily used for collecting "real-time" sequences of experimental data, where timing is critical and events cannot be missed. Once the PI-MAX4 has been issued the Start Acquisition command by the computer, all frames are collected without further intervention from the computer. The advantage of this timing mode is that timing is controlled completely through hardware. A drawback to this mode is that the computer will only display frames when it is not performing other tasks. Image display has a lower priority, so the image on the screen may lag several images behind. A second drawback is that a data overrun may occur if the number of images collected exceeds the amount of allocated RAM or if the computer cannot keep up with the data rate.

— **Safe Mode**

Safe mode is primarily useful for experiment setup, including alignment and focusing, when it is necessary to have the most current image displayed on the screen. It is also useful when data collection must be coordinated with external devices such as external shutters and filter wheels. As seen in Figure 5-22, the computer controls when each frame is taken. After each frame is received, the camera issue a **Stop Acquisition** command to the camera, instructing it to stop acquisition. Once that frame has been completely processed and displayed, another Start Acquisition command is issued from the computer to the camera, allowing it to take the next frame. The display is therefore, at most, one frame behind the actual data collection.

One disadvantage of Safe mode is that events may be missed during the experiment since the PI-MAX4 is disabled for a short time following the acquisition of each frame.

• **Delay Time**
This parameter allows a delay to be inserted between successive frame acquisitions. This parameter is only active when operating in Safe Mode where each frame must be completely processed before the next one can be acquired. The Delay Time inserts an additional delay after the computer has finished processing the previous frame before the next one can be acquired.

5.14   LightField Experiment Setup

Initial experiment setup for LightField is an easy process. If the PI-MAX4 is powered on when LightField is launched, the camera will automatically be detected and its icon will be placed in the **Available Devices** area. When the camera icon is dragged into the **Experiment Devices** area, the appropriate expanders are loaded in the **Experiment Settings** stack. If this is the first time LightField has been launched with this specific camera, the default settings for the camera will have been loaded into the expanders.

The following sections provide brief descriptions of many **Experiment Settings** expanders.

📖 **REFERENCES:**

For detailed information about each expander, refer to the LightField User's Manual and LightField's online help.

5.14.1   Common Acquisition Settings Expander

Figure 5-23 illustrates a typical Common Acquisition Settings expander.

Figure 5-23: Typical Common Acquisition Settings Expander
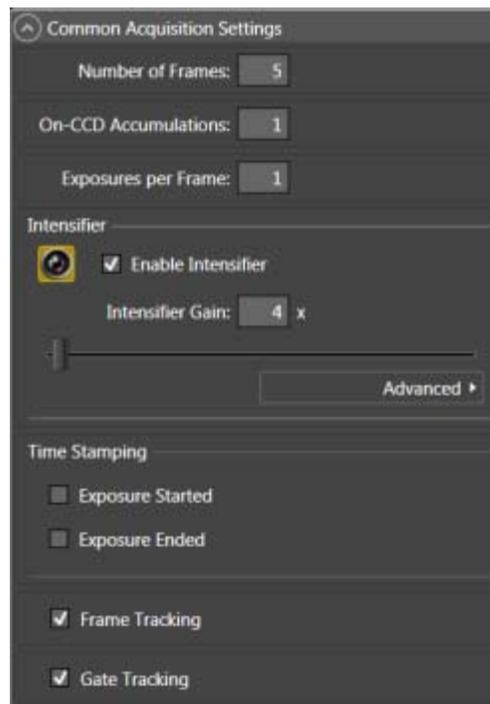
4411-0137_0042

From this expander, the following parameters are configured:

- **Number of Frames**
  Configures how many images will be acquired.
- **On-CCD Accumulations**
  Configures whether multiple frames will be used to create a single frame.
- **Exposures per Frame**
  Configures whether multiple exposures will occur while a frame is being acquired.
- **Enable Intensifier** check box
  When checked, the Intensifier is enabled.

- **Intensifier Gain**
  Configures the level of Intensifier Gain.

- **Advanced** fly-out
  The following advanced parameters are accessed within this fly-out:
  — **Phosphor Decay Delay Time**
  — **Resolution**

- **Time Stamping**
  Configures which, if any, of the following time stamp information is to be stored and displayed with the data:
  — **Exposure Started** time;
  — **Exposure Ended** time.

5.14.2   Region of Interest Expander

Figure 5-24 illustrates a typical Region of Interest expander.

Figure 5-24: Typical Region of Interest Expander

4411-0137_0043

The **Region of Interest** expander is used to configure how much of the total sensor image area will be used to acquire the data (i.e., full sensor, or one or more regions of interest.)

Hardware or software binning are configured on this expander. The **Advanced** button opens a fly-out panel where the type of binning (hardware or software) to be used is configured when bin values other than 1 have been specified.

The **Edit ROIs** button opens the **Edit Regions of Interest** window where a reference image can be captured to help define which area (or areas) on the sensor are to be included when data acquisition is started. A selection box may be drawn to define an area, or specific values may be entered into the ROI fields.

5.14.3 Trigger Expander

The **Trigger** expander is used to configure the trigger source to be used for trigger gating. Valid sources for the Trigger Input are:

- **Internal**
  Figure 5-25 illustrates typical configuration parameters for Internal triggering.

Figure 5-25: Typical Trigger Expander: Internal Trigger Source Parameters
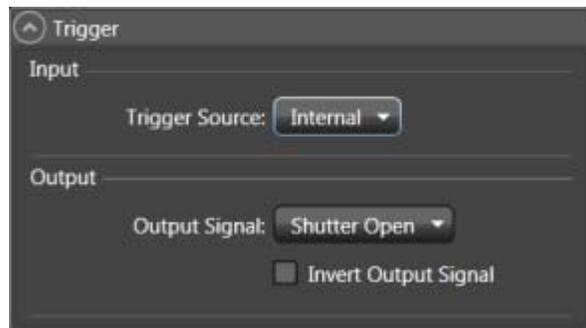
4411-0137_0044

Internal triggering uses the user-specified **Internal Trigger Frequency** that has been selected on the **SuperSYNCHRO Timing** expander. Refer to Section 5.14.4, SuperSYNCHRO Timing Expander, for additional information.

- **External**
  Figure 5-26 illustrates typical configuration parameters for External triggering.

Figure 5-26: Typical Trigger Expander: External Trigger Source Parameters
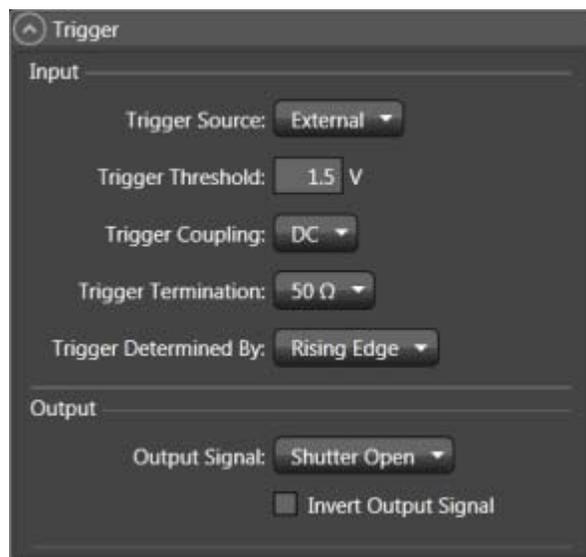
4411-0137_0045

External triggering requires that an external trigger be defined so LightField will be able to recognize it when it occurs at the **TRIGGER IN** BNC on the rear of the PI-MAX4 device.

In addition, the logic level for the **LOGIC OUT** signal is also defined on this expander.

5.14.4 SuperSYNCHRO Timing Expander

The **Super SYNCHRO Timing** expander is located at the bottom of the LightField desktop. See Figure 5-27.

> **NOTE:**
>
> The top of the **SuperSYNCHRO Timing** expander can be:
>
> - Dragged up to view more of the **SuperSYNCHRO** panel;
> - Dragged down to view more of the **Experiment Settings** stack or the **Device/View** panel.

Figure 5-27: SuperSYNCHRO Timing Expander
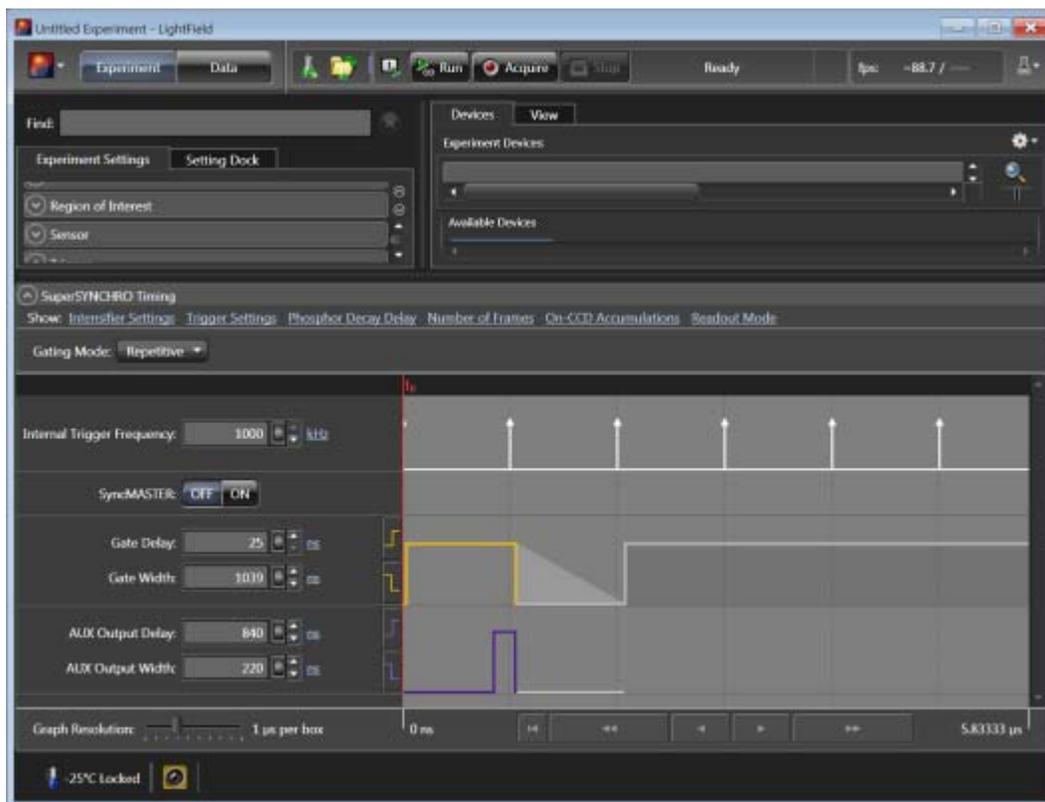
4411-0137_0046

This expander is used to access and configure parameters such as:

- **Gating Mode**;
  Valid values for PI-MAX4 are:
  — Repetitive;
  — Sequential;
  — DIF.
- **Gate Delay**;
- **Gate Width**;
- **AUX Output Delay**;
- **AUX Output Width**.

When **Internal Trigger** is the selected Trigger Source or **SyncMASTER** is turned on, the **Internal Trigger Frequency** can also be configured.

Hyperlinks are also provided which open the appropriate expanders for quick access to configuration settings for:

- Intensifier;
- Trigger;
- Phosphor Decay Delay;
- Number of Frames;
- On-CCD Accumulations;
- Readout Mode.

Chapter 6: LightField and Gated Operation

This chapter discusses gated operation with the SuperSYNCHRO™ timing generator as well as aspects of PI-MAX4 operation that are not covered in

should also be reviewed since it provides helpful information about how to achieve desired results when performing more complex measurements.

6.1 Gating

Gating provides electronic shutter action by controlling the photocathode bias, allowing the detection of low light level signals in the presence of interfering light sources of much greater energy. For instance, in combustion research, a pulsed laser probe is used to investigate the chemistry within a flame. Since the flame itself emits broadband light continuously, the integrated flame emission is much greater than the integrated signal resulting shortly after the laser probe (e.g., laser-induced fluorescence or Raman.) Fortunately, since the laser pulse is very short and the time at which it occurs is known, it is possible to gate for a few nanoseconds during the laser pulse, thus reducing the flame emission interference by approximately the measurement duty factor ratio.

Exposure time is the 'time space' from which charge integrating on the CCD will get summed into the reported data. Gate width is the time during which light will be detected by the intensifier, intensified, and applied to the CCD. Basically, the intensifier controls what the chip 'sees' during the exposure time.

For a signal to be detected, it must fall in a valid gate width during a valid exposure. Many gate pulses can be placed into one exposure at repetitive or sequential intervals because there is no temporal measure inside a given exposure [i.e., all incident signals are summed (integrated) into one value per pixel/super pixel inside a given exposure.]

Using currently available image intensifiers and gate pulse generators, optical gate times ≤ 4 ns FWHM (full width at half maximum) are possible. Since the control is electronic, the gate width can be made virtually as long as desired, allowing a wide range of experiment requirements to be satisfied in one instrument setup. Further, during UV measurements where the On:Off ratio is only 10^4:1, the PI-MAX4's MCP bracketing feature can be used to extend the On:Off ratio to 10^6:1.

6.2   Safety Precautions

When biased ON, intensified CCD cameras such as the PI-MAX4 can be permanently damaged if continuously exposed to light levels exceeding twice the A/D saturation level. It is **critical** that a camera **not** be operated under lighting conditions which may damage the intensifier.

Although intensified cameras operating in gated mode are less prone to damage from **background light**, they are at **significant risk** of damage from high-intensity light sources such as LASERs. High intensity sources can damage an intensifier before protection circuits have time to respond. Spot damage may result without the protection circuits acting at all.

If a sustained alarm indication occurs when the controller is turned on, immediately turn the **I.I.T.** switch on the back of the PI-MAX4 to the **OFF** position. Cover the camera's window, and only after the illumination level has been lowered to safe operating conditions can the **I.I.T.** switch be turned **ON**.

6.2.1   Intensifier Mode

Within LightField, the intensifier is enabled/disabled on the **Common Acquisition Settings** expander:

- When the intensifier is enabled, the camera can be gated;
- When the intensifier is disabled, the photocathode is continuously biased OFF, and the intenser is as safe as it can be.

NOTE:

In order for gating to occur, the I.I.T. switch on the back of the PI-MAX4 must be in the **ON** position.

6.2.2   Alarms

NOTE:

It is normal for an alarm to sound briefly when the system is initially turned on.

To reduce the risk of camera damage, the PI-MAX4 camera is equipped with an audible alarm in the camera head, activated when the intensity of light falling on the image intensifier exceeds a preset threshold. While the alarm is sounding, the photocathode is disabled. Immediately toggle the **I.I.T.** switch (on the back of the PI-MAX4) to the **OFF** position. Cover the camera window and only switch the **I.I.T.** switch to **ON** after the illumination level has been lowered. If the alarm sounds continuously even when the illumination level is adequately low, shut the system down and contact the factory for guidance.

⚠️ **CAUTION!**

Discontinue operation and contact the factory at once if sporadic or continuous unwarranted alarms occur. They may indicate intensifier damage or another situation that requires immediate attention.

6.3 Timing Mode

In **Gate Mode**, the internal timing generator uses **Internal Sync** timing which initiates a readout cycle following each internally-generated timing pulse sequence.[1]

Internal handshakes are used to prevent:

- A readout from being initiated when the timing generator is busy;
- Biasing the photocathode ON while a readout cycle is in progress.

The following camera parameters are automatically configured by WinX and cannot be changed:

- **Exposure Time**: Set to 0;
- **Continuous Cleans**: disabled;
- **Shutter Control**: Disabled Opened.

NOTE:

> These parameters may not be visible in some versions of the application software.

Refer to Table 6-1 for additional Internal Sync information when using Gated mode.

Table 6-1: Internal Sync Information for Gated Operation

Timing Mode	Shutter Control	Ext. Trigger Input
Controlled by Internal Timing Generator	Controlled by Internal Timing Generator	Trigger In BNC

NOTE:

> The **Accumulations** and **Images** (or **Spectra**) parameters (WinView/32 or WinSpec/32 Acquisition Setup **Main** tab) determine how data will be processed. Integrating multiple events on the CCD really brings the power of the PI-MAX4 to bear on low-light gate-mode experiments. If the experiment allows, many pulses can be summed on the CCD with no pulse artifacts in the readout. The signal increases nearly linearly with the number of pulses (within limits imposed by the CCD.)

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1. An internal timing generator pulse sequence consists of a Gate Start pulse, a Gate Stop pulse, and one or more Auxiliary pulses.

6.4 Micro-Channel Plate (MCP) Bracket Pulsing

The primary advantage gained from incorporating gating is that it allows temporal discrimination against background light. By allowing the photocathode to "see" only during the event of interest, very high background illumination levels can be tolerated without materially degrading experiment results. Limits for this technique are determined by the light leakage of the intensifier, which, although very good, is not without bounds.

- Within the visible spectrum, the on/off ratio of a typical Gen II Intensifier with just the photocathode gated is excellent, typically between 10^6 and 10^7. For most measurements, this ratio is more than adequate to guarantee that any signal reaching the CCD during intensifier Off times is too small to affect the data.

- However, when working with wavelengths below 350 nm, optical leakage through the photocathode to the UV-sensitive MCP occurs. At 200 nm, the on/off ratio is reduced to approximately 2×10^4. This is the dominant response of a Gen II image intensifier to UV photons when the photocathode is electrically off. At an On/Off ratio of 20,000, the ability of a camera with conventional photocathode (only) gating to perform certain kinds of measurements in the UV is adversely affected.

MCP bracket pulsing[1] keeps the MCP biased OFF except for an interval that brackets the timing of the photocathode gate as shown in Figure 6-1.

Figure 6-1: Timing Diagram: MCP Bracket Pulsing

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For emitted photoelectrons to be accelerated in the MCP, the MCP must be biased ON. In conventional intensified cameras, the MCP is biased ON continuously. In PI-MAX4, however, when bracket pulsing is ON, the MCP is biased OFF until just before the photocathode is gated ON and is biased OFF shortly after the photocathode is biased OFF.

By bracket pulsing the MCP off (in addition to photocathode gating,) the on/off ratio of the Gen II PI-MAX4 in UV is improved by two to three orders of magnitude. The resulting UV ratio exceeds even the high levels normally achieved in the visible. Applications that benefit from this new approach include LIF and nanosecond pump-probe experiments.

NOTE:

Bracket pulsing does not help in the visible region. Under extremely low duty-factor conditions, the only remedy is to install an external shutter ahead of the camera.

---

1. Bracket pulsing is not available for cameras having a filmless Gen III Intensifier. Gen III Intensifiers do not respond in the UV.

6.4.1   Bracket Pulsing in LIF Measurements

Most experiments using laser-induced fluorescence to probe combustion flows are performed with UV probe/lasers. Atomic emission from flames also has significant UV content. If the flame is continuous, the UV background will also be continuous. Even where a flame is transient (e.g. internal combustion engine,) its lifetime can be many milliseconds, compared to the nanosecond time scale of the laser used. This background can be a million times as long. If the background is bright, then a UV on/off ratio of 20,000:1 will be overwhelmed by the duty cycle and will not be adequate for extracting a signal of 10^{-5}. In high dynamic range quantitative measurements, backgrounds must be kept to an absolute minimum. MCP bracket pulse gating dramatically improves the rejection of CW and even millisecond time-scale background.

An alternative to suppressing background for imaging has been the use of very narrow spectral bandpass filters. In the UV, these filters are expensive and they can have low transmission at their central wavelength. An additional filter is required for each wavelength to be imaged. The use of electronic temporal rejection of CW or quasi-CW background may make it unnecessary to use these filters, thus increasing the optical throughput, sensitivity, and quantitative precision of the measurement.

6.4.2   Bracket Pulsing in Nanosecond Pump Probe Experiments

Some nanosecond pump-probe experiments combine a nanosecond or faster pump with a flashlamp probe. The duration of the probe flash can be 10-50 µs and a gate is used to select the specific nanosecond-scale time slice to be observed within the much longer probe flash. In these absorbance experiments, accurate measurement of absorbance values depends critically on the lack of stray light contamination, particularly at moderate to high optical density levels. Selecting a 5 ns time window out of a 10 µs pulse is already one part in 2,000. If UV leakage gives an on/off ratio of only 20,000:1, contamination could be 10% of higher. This would limit the optical density to 1.0, and it could make linear quantitation difficult beyond 0.1 OD.

MCP bracket pulse gating can substantially improve the on/off ratio in such an experiment. Even with a 1 µs MCP pulse, the rejection of flash-lamp leakage can add more than an order of magnitude of range, to 2.0 OD.

6.4.3   Limitations of Bracket Pulse Gating

MCP bracket pulse gating is most useful in rejecting background that lasts microseconds up to CW. Fast transient backgrounds can be in the form of stray laser light scattering (Raleigh, MIE, Raman) or unwanted fast fluorescence. Because these usually fall below the MCP bracket pulsing 35 ns delay restriction, these measurements cannot be improved much by MCP bracket pulsing in the PI-MAX4.

Electrically, gating the MCP will only reduce leakage at wavelengths where the MCP has photoelectric response (primarily in the UV.) Thus, for visible and NIR wavelengths where leakage is primarily optical, the improvement will be minimal (although the on/off ratio is already very good in these regions.) Note that in some spectroscopic applications, visible leakage may appear to be reduced by MCP pulsing. This is because the second order UV spectrum overlays the first order visible spectrum in a grating spectrograph. MCP pulsing can eliminate unwanted sensitivity to CW or quasi-CW second order UV, causing the apparent improvement.

Also, keep in mind that MCP bracket pulsing adds 10 ns delay to the photocathode gating. Even though the bracket timing is controlled automatically by the software, in an experiment where it is necessary to delay the arrival of the laser pulse at the sample, this will mean inserting an additional delay of 10 ns (min gate delay = ~25 ns, with bracket = 35 ns) to accomplish coincidence at the camera. MCP bracketing should only be used in experiments where it is going to make a difference.

Also, MCP bracket gating limits the repetition rate to 6.25 kHz, without it the gate repetition rate can be up to 1 MHz (more with option boards.) This is not a significant limitation in most cases. Note that with a 10 ns gate at 6.25 kHz, the on/off ratio = 16,000, close to the non-bracket value.

Note that background light need not be the limiting factor in measurements where MCP bracket pulsing is unable to provide the required degree of rejection. In such measurements, the option remains of installing an external shutter ahead of the PI-MAX4.

6.4.4   Impact of Bracket Pulsing on Delay

If operating in the UV when bracket pulsing is activated (Gen II Intensifier only,) the MCP gate automatically brackets the photocathode gate pulse to further enhance the on/off ratio. There is, however, a limitation of bracket pulsing that can complicate the coincidence of the signal and gate at the camera. Because MCP bracket gating is slower than photocathode gating (35 ns is required to gate the MCP on and another 1 µs to gate the MCP off at the end of the photocathode gate.) As a result, MCP bracket pulsing should not be used in experiments where the delay between the trigger and the photocathode gate is less than 35 ns.

6.4.5   Configuration

MCP Bracket pulse implementation is enabled by selecting **Bracket Pulsing ON** from within the host software. Figure 6-2 illustrates the timing diagram for bracket pulsing.

> **NOTE:**
>
> Because **Gen III** Intensifiers do not respond in the UV, bracket pulsing is not available for these intensifiers.

Figure 6-2:   Timing Diagram: MCP Bracket Pulsing
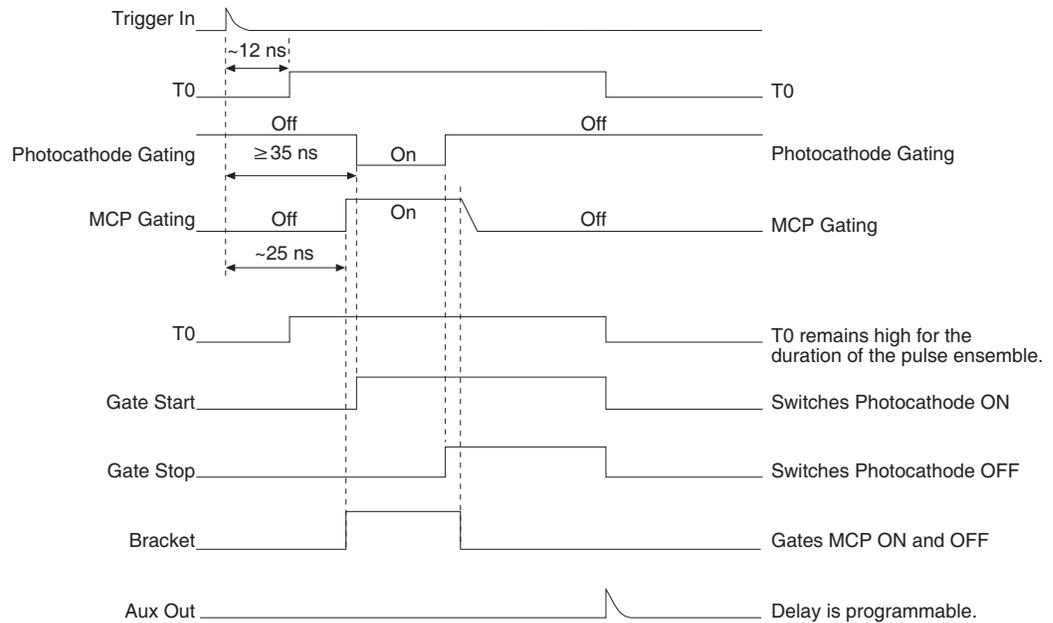
4411-0137_0048

As shown in Figure 6-2, the insertion delay between **Trigger In** and **T0** is approximately 12 ns, and the insertion delay between **Trigger In** and **Photocathode Gating** is 35 ns.

> **NOTE:**
>
> The minimum delay between **Trigger In** and **Photocathode Gating** in bracket mode is 35 ns in order to allow the MCP to achieve full gain before the photocathode is gated on.

6.5 Experiments

Figure 6-3illustrates a breakdown of the types of experiments that can be performed with a PI-MAX4 camera.

Figure 6-3: Typical PI-MAX4 Experiments

4411-0137_0049

Most gated measurements that can be performed with a PI-MAX4 will fall in one of the following categories:

- **Static Gate**

  This type of experiment may also be referred to as "Repetitive-Continuous." There is a repetitive trigger, and the Gate Width and Gate Delay are fixed. Some variable in the experiment such as pressure, concentration, wavelength, or temperature, are varied.

- **Swept Gate**

  In this type of experiment, Gate Width and/or Gate Delay may be varied.

  — Repetitive-Sequential 1

  The Trigger is repetitive, Gate Width is fixed, and Delay is varied over the course of the measurement. The result of the experiment is a plot of intensity vs. time, such as might be obtained with a sampling oscilloscope. This technique is used to measure lifetime decays.

  — Repetitive-Sequential 2

  The Trigger is repetitive and Gate Width and Delay are varied over the course of the measurement. Gate Width and Delay can be incremented in a linear fashion or in an exponential fashion. Increasing the Gate Width is useful for trying to find fine detail in a weak decaying signal. If you choose linear, you have to take a lot more points. Exponential lets you take data points closer together where the signal is changing rapidly and further apart where the signal is changing slowly.

- **Single Shot**
  A single shot experiment is one where there is only one chance to obtain the data. Any experiment that can not be repeated more often than once a minute, such as high power lasers and explosives, is considered a single shot. You have to catch the trigger when it comes. Prior to the event, the sensor runs in **Clean Until Trigger** mode. This must be active otherwise dark current can accumulate on the sensor. When the trigger arrives, the cleans stop, the intensifier gates, and the array is read out with a minimum of dark current.

Refer to the following sections for information about conducting the indicated experiments:

- Section 6.5.1, Swept Gate Experiment [Fixed Width, Variable Delay];
- Section 6.5.2, Single Shot Experiment;
- Section 6.5.3, Swept Gate Experiment [Variable Width, Variable Delay];
- Section 6.5.4, Static Gate Experiment [Fixed Width, Fixed Delay].

6.5.1   Swept Gate Experiment [Fixed Width, Variable Delay]

This experiment is an attempt to time-resolve a Xenon light flash from a commercially available strobe light.

6.5.1.1   *Experiment Supplies the Master Clock*

Since the strobe does not have a "pre-trigger" out, an electrical trigger is generated by using a photodiode. Output from the photodiode is connected to the **Trigger In** BNC on the PI-MAX4.

Perform the following procedure to time-resolve a Xenon light flash from a commercially available strobe light:

1. Setup all equipment as illustrated in Figure 6-4. Timing diagrams are also provided for reference.

NOTE:

This procedure uses the experiment as the Master Clock. See Figure 6-4 for hardware connection information.

Figure 6-4: Block/Timing Diagram: Swept Gate Experiment
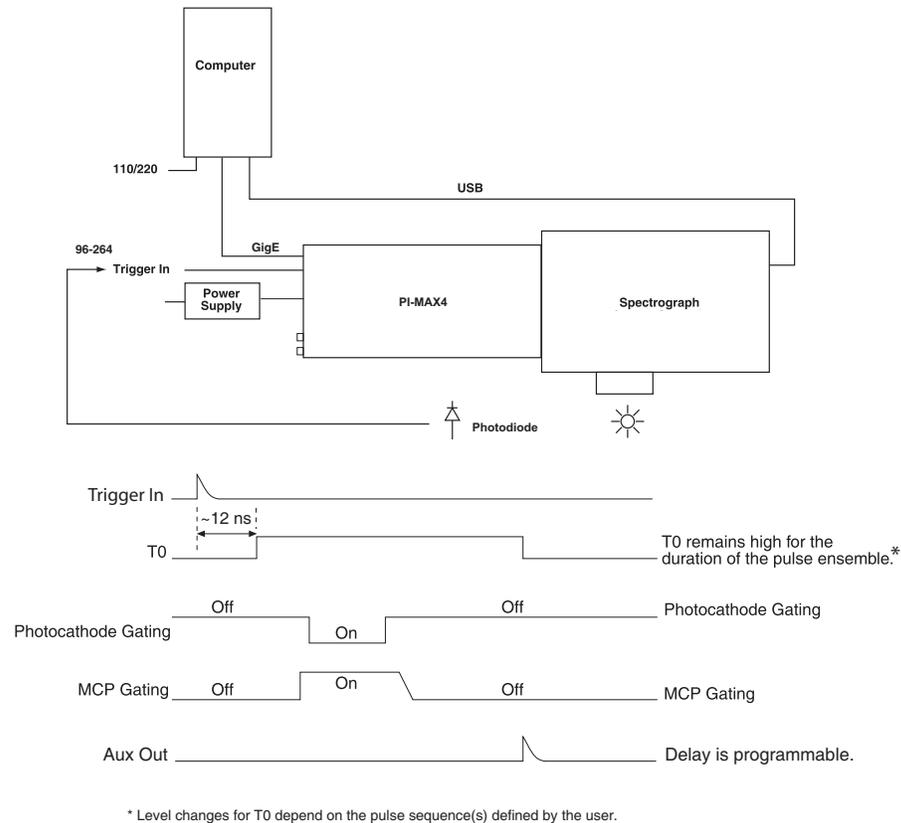
4411-0137_0050

2. Turn on all equipment and launch LightField.

3. Open the **Sensor** expander and click on the **Sensor Cleaning** button. See Figure 6-5.

Figure 6-5: Typical Sensor Cleaning Fly-out Pane
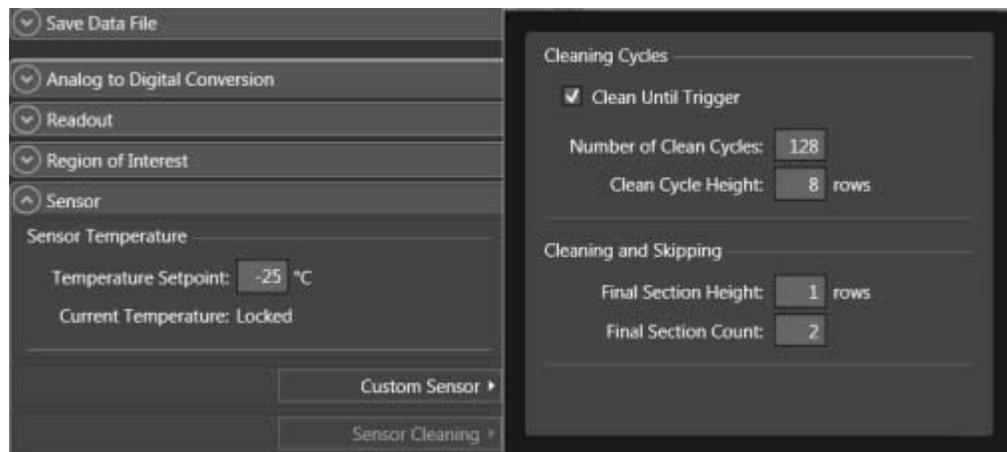
4411-0137_0070

a. If one or more orange reset button are displayed on the fly-out pane, click on them to reset to their default values.

b. Configure the camera's temperature, in degrees Celsius, by configuring the **Target Setpoint** field on the **Sensor** expander.

4. When using an Acton SpectraPro Series spectrograph, verify it was turned on when LightField was launched.

If using an LS-785, an icon should be shown in the **Available Devices** area.

When the spectrograph icon is dragged into the **Experiment Devices** area, the **Spectrometer** expander is added to the **Experiment Settings** stack with appropriate parameters provided. See Figure 6-6 for typical expanders.

Figure 6-6: Typical Spectrometer Expanders
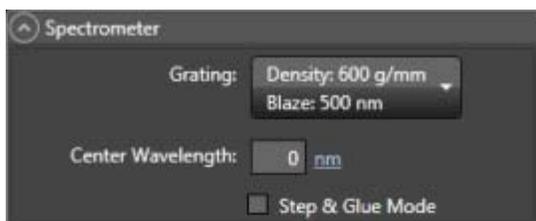
ACTON SPECTRAPRO SERIES SPECTROGRAPH
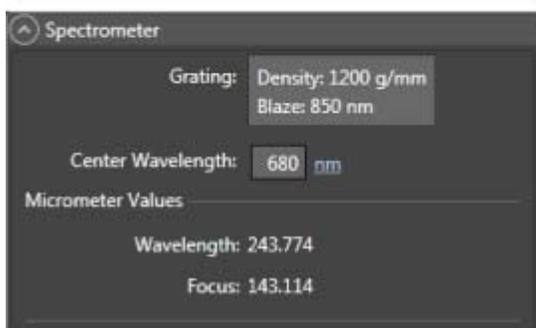
LS785 SPECTROGRAPH

4411-0137_0071

5. Move the grating to the desired wavelength.

6. On the **Region of Interest** expander, select **Full Sensor**. See Figure 6-7.

Figure 6-7: Typical Region of Interest Expander: Full Sensor

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7. Verify that the camera is operating and is properly focused by running it in "Internal Trigger" mode.

Perform the following procedure to run in **Internal Trigger** mode to verify camera focus:

a. On the **Common Acquisition Settings** expander, within the **Intensifier** section, configure the following parameters:

- **Enable Intensifier**: check the associated box;
- **Intensifier Gain**: Enter a value between **1** and **100**, inclusive.

See Figure 6-8.

Figure 6-8: Typical Common Acquisition Settings Expander
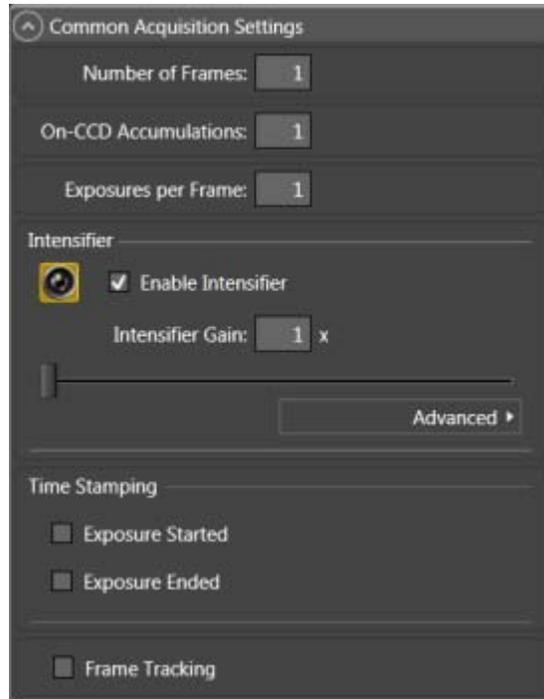
4411-0137_0073

b. Within the **Analog to Digital Conversion** expander, configure the following parameters:

- **Speed**;
- **Analog Gain**

See Figure 6-9.

Figure 6-9: Typical Analog to Digital Conversion Expander
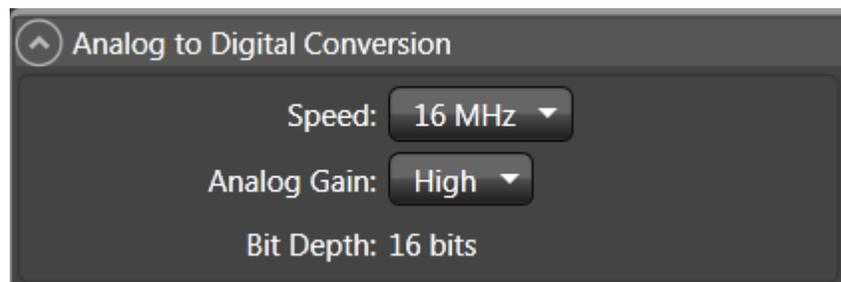
4411-0137_0074

    c. On the Trigger expander, configure the following parameters as indicated:

        • **Trigger Source**: **Internal**.

    See Figure 6-10.

Figure 6-10: Typical Trigger Expander
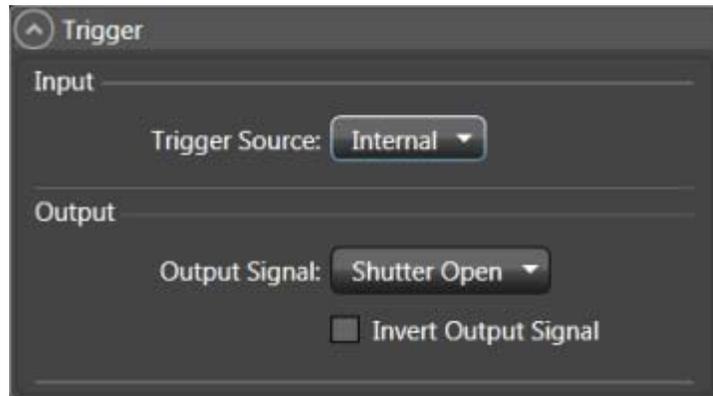
4411-0137_0075

    d. Verify the ambient light level is low. Adjust the light level as required.

    e. If necessary, click on the **View** tab to bring it to the front, and then click on the **Run** button.

    f. The camera will begin acquiring data.

> **NOTE:**
>
> Data collected at this time will not be saved.

    g. Once it has been verified that the camera is operating properly and is in focus, halt data acquisition.

8. On the **Region of Interest** expander, configure the following parameters as indicated:
   - Select **Full Sensor, Binned** [radio button];
   - **Bin H**: **1024**.

See Figure 6-11.

Figure 6-11: Typical Region of Interest Expander: Full Sensor Binned
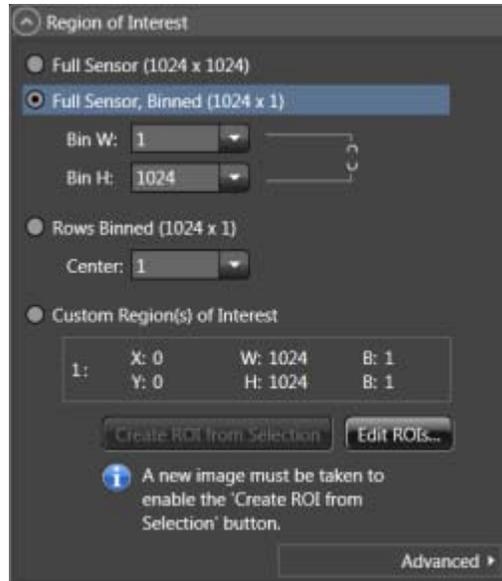
4411-0137_0076

9. On the **Trigger** expander, configure the following parameters as indicated:
   - **Trigger Source**: **External**;
   - **Trigger Threshold**: **1.5**;
   - **Trigger Coupling**: **DC**;
   - **Trigger Termination**: **50 Ω**;
   - **Trigger Determined By**: **Rising Edge**;

See Figure 6-12.

Figure 6-12: Trigger Expander: External Trigger Source Configuration
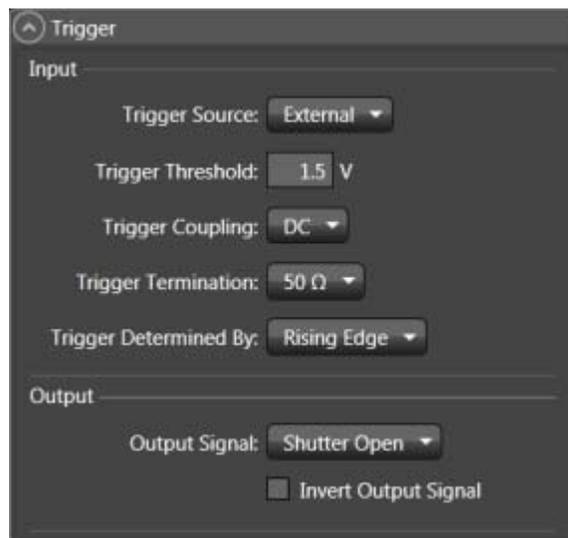
4411-0137_0077

10. Open the **SuperSYNCHRO Timing** expander (located above the Status bar.)
See Figure 6-13.

Figure 6-13: Typical SuperSYNCHRO Timing Expander
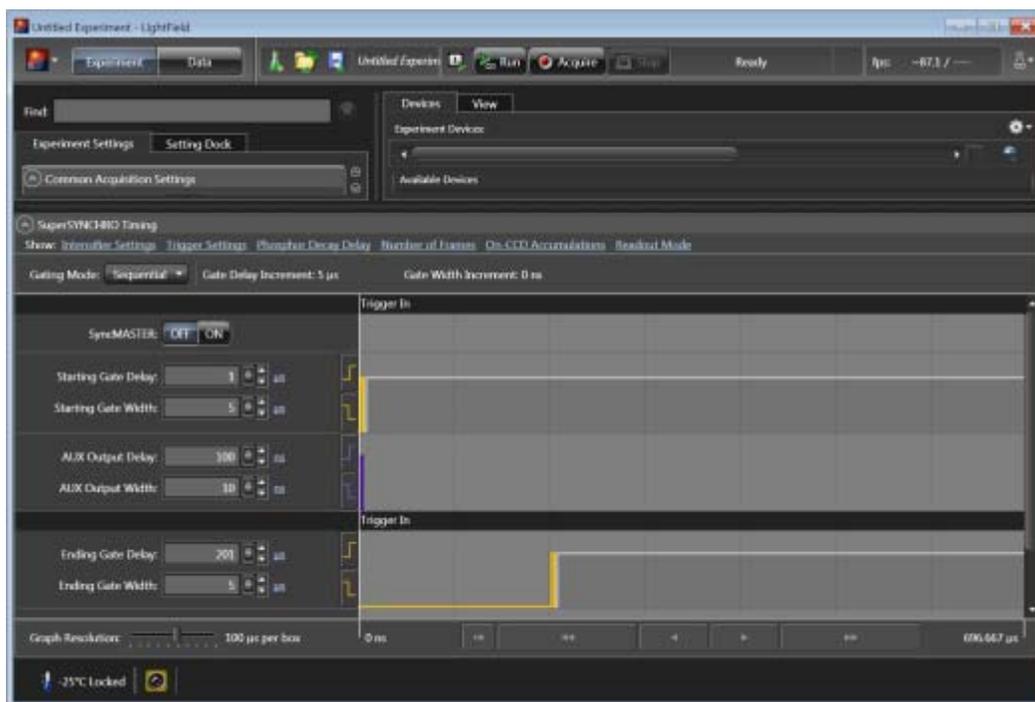
4411-0137_0078

Perform the following procedure to configure gate timing parameters as indicated:

a.   Gating Mode: Sequential

If using a Gen II intensifier, configure **Bracket Pulsing** to **OFF** for this experiment.

b.   Perform the following procedure to configure the pulse sequence:

- Click on the **Number of Frames** hyperlink. Enter the number of frames to be acquired (e.g., **41** for this experiment.)
- Configure the **Starting Gate Width** and **Ending Gate Width**.
  Because this experiment requires a fixed gate width, these values will be the same.
- **Starting Gate Delay**: **1 μs**;
- **Ending Gate Delay**: **201 μs**;
- Click on the **On-CCD Accumulations** hyperlink. Enter the number of **On-CCD Accumulations** per frame (e.g., **1** for this experiment.)

c. The **SyncMASTER ON** button enables the SyncMASTER trigger output from the SyncMASTER1 and SyncMASTER2 connectors on the **AUX I/O** cable. The frequency for the SyncMASTER outputs may then be configured, as well as the AUX Output signal at the AUX OUT connector on the rear of the PI-MAX4.

- When **SyncMASTER** is enabled, the output of the SyncMASTER1 connector will be at the frequency specified on the Internal Trigger Frequency field.
- The output of the **SyncMASTER2** connector will be at the same frequency as that of **SyncMASTER1**. However, a delay can be specified so the edges of **SyncMASTER2** will occur after the edges of **SyncMASTER1**.
- When using the AUX Output signal from the SuperSYNCHRO to trigger a piece of equipment, enter the Auxiliary pulse delay time. Enter the pulse width needed to trigger the equipment.

Figure 6-14 illustrates SuperSYNCHRO Timing with SyncMASTER on.

Figure 6-14: Typical SuperSYNCHRO Timing: SyncMASTER On

4411-0137_0079
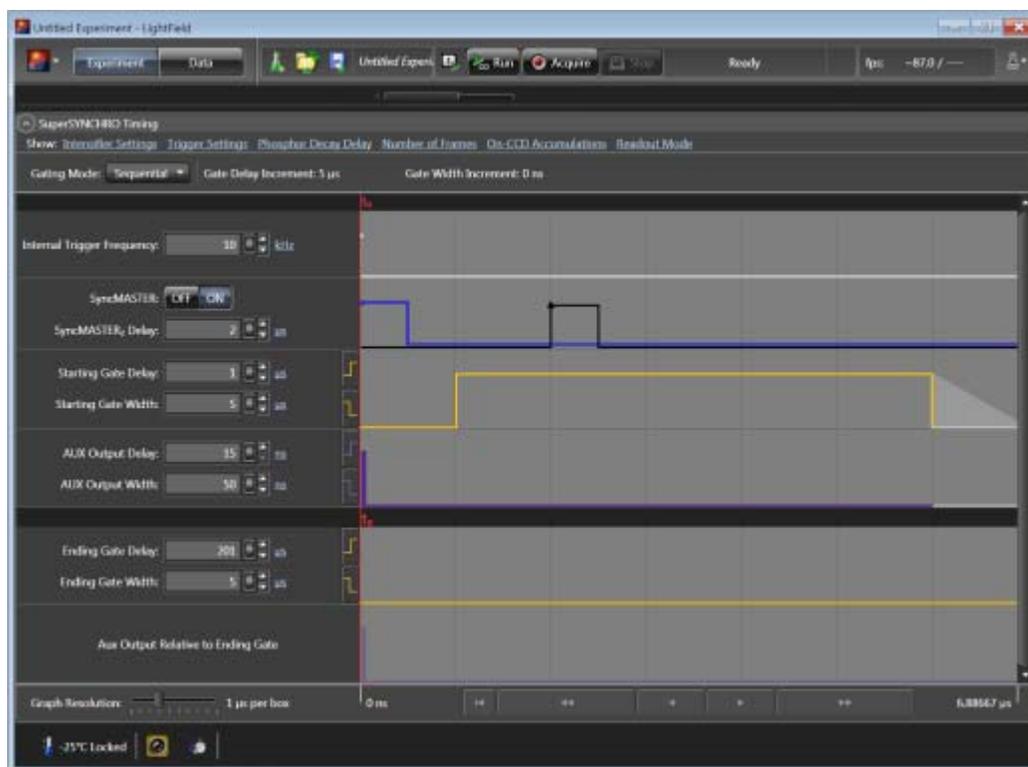
11. After verifying all connections and equipment readiness, collapse the **SuperSYNCHRO Timing** expander.

12. If necessary, click on the **View** tab to bring it to the front, and click on **Acquire** to begin acquiring spectra or images.

> **NOTE:**
>
> The photocathode is biased on only for the time that each gate pulse is applied. This limits the risk of damage resulting from room light. However, there is a risk of damaging overload from intense light sources such as lasers.

13. Figure 6-15 illustrates the graph for a **Sequential -Repetitive** experiment with fixed width and variable delay. **Show Frame Cross Section** has been selected. The intensity of the selected point was at it maximum in Frame 23.

Figure 6-15: Typical Experiment Results: Frame Cross Section
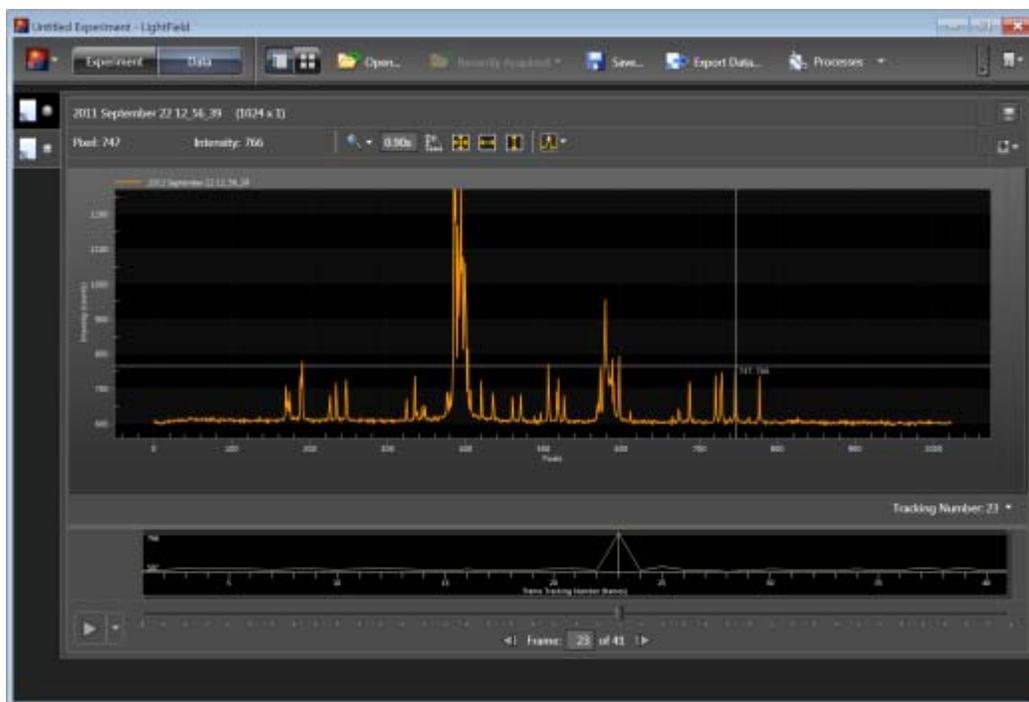
4411-0137_0080

6.5.1.2   SyncMASTER1 Supplies the Master Clock

When using a light source that has a **Trigger In**, the PI-MAX4 SyncMASTER function can be used as the Master clock. The setup procedure is similar that described in Section 6.5.1.1, Experiment Supplies the Master Clock, with the following changes:

- **Internal Trigger** is selected;
- **SyncMASTER** is enabled;
- A cable is required between the PI-MAX4 AUX I/O cable SyncMASTER1 BNC and the light source (i.e., experiment,) for triggering the event. See Figure 6-16

Figure 6-16: Block Diagram: SyncMASTER1 as Master Clock
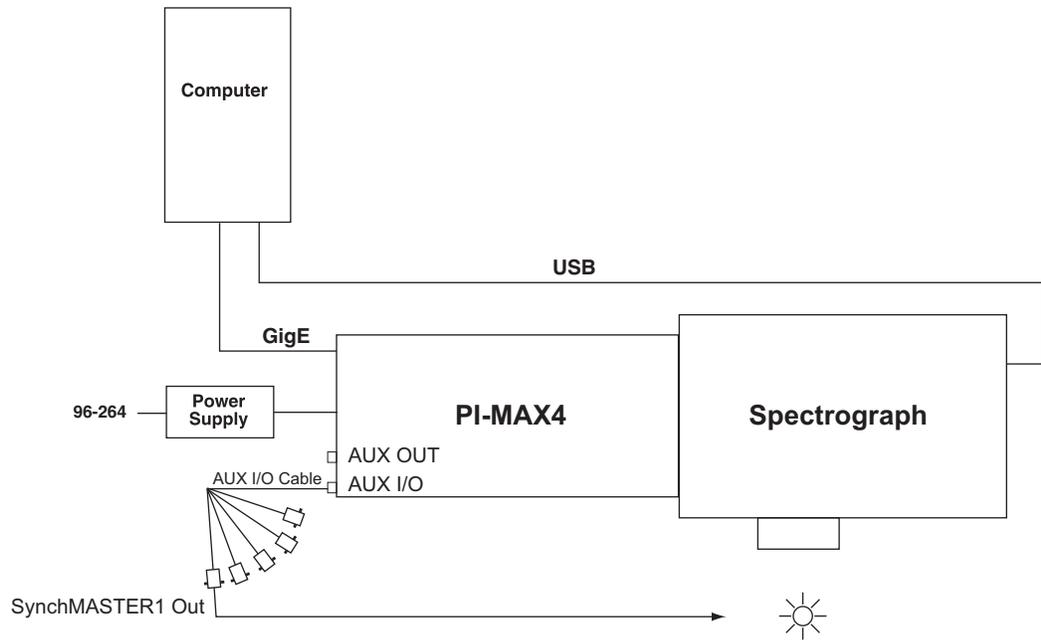
4411-0137_0062

Figure 6-17 illustrates the timing diagram for this experiment configuration.

Figure 6-17: Timing Diagram: SyncMASTER1 as Master Clock
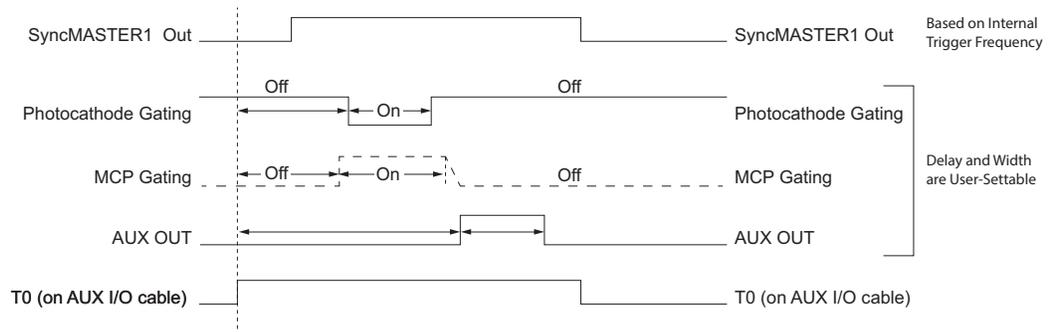
4411-0137_0063

6.5.2   Single Shot Experiment

A single shot experiment offers only one chance to capture an event. As with any gated experiment, the time budget of the experiment is critical. If there is no pre-trigger from the experiment, a photodiode can be used to generate an electrical trigger from the laser light. In this situation, light has to be delayed by optical means (e.g., fiber-optic cable or mirror reflections,) to allow sufficient time for the electronics to be activated after having received the trigger. Another important thing to note in single shot experiments is that **Sensor Cleaning** is configured for **Clean Until Trigger** so that there is no dark charge accumulation while it waits for the trigger.

This experiment is an attempt to capture a 60 ns fluorescence generated by a single shot laser. The time budget of the experiment is detailed in Table 6-2. This information is important in order to choose the correct length fiber optic cable.

Table 6-2:   **Single Shot Experiment Time Budget**

Delay Source	Delay (ns)	Total Delay (ns)	Fiber Optic Cable Length
Photodiode (light -> TTL pulse)	2	30	A minimum of 21 ft of fiber optic cable is required.
Photodiode -> PI-MAX4 (2 ft BNC cable)	3		
PI-MAX4	25		

In this experiment, cable lengths are kept to a minimum so that the length of the fiber optic cable required may also be minimized.

Figure 6-18 provides a block diagram of the hardware setup for a single shot experiment.

Figure 6-18: Block Diagram: Single Shot Experiment

4411-0137_0064
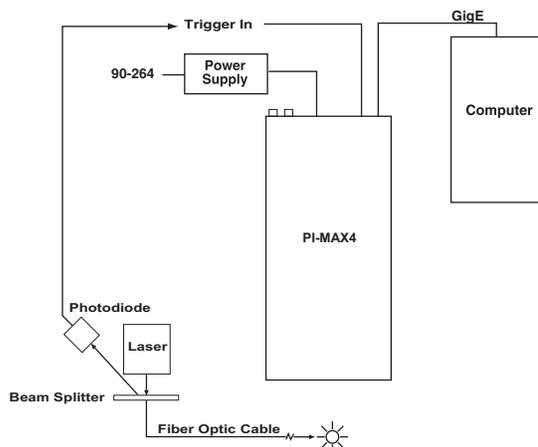
Once the equipment has been set up, default values for **Cleaning Cycles** and **Cleaning and Skipping** are configured. See Figure 6-19.

> 🔍 **NOTE:** ─────────────────
>
> If PI-MAX4 has to wait more than a few seconds for an external trigger, it is advisable to increase the number of cleans.

Figure 6-19: Cleaning Cycles, Cleaning and Skipping Expander
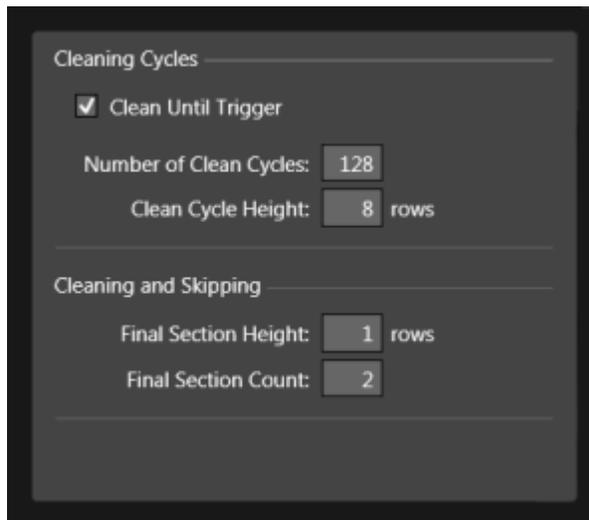
4411-0137_0081

The sequence of operations is similar to that for Sequential experiments. After focusing the camera on the fluorescing sample, an appropriate **Gain** is configured. See Figure 6-20.

Figure 6-20: Common Acquisition Settings Expander: Intensifier Gain
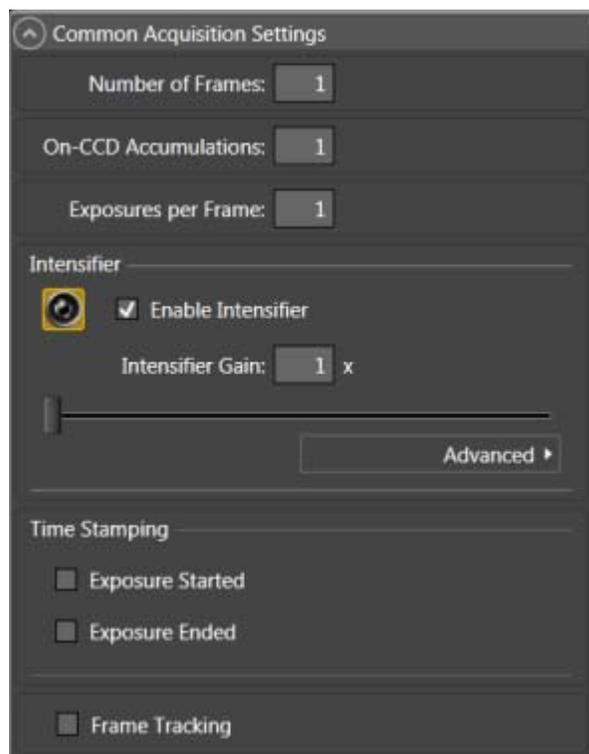
4411-0137_0073

Gate Width and **Gate Delay** should be configured so that the intensifier is gated **ON** during the entire event. For example, in this case the event is a 60 ns fluorescence. See Figure 6-21.

Figure 6-21: Typical Repetitive Gating Setup: 100 ns Width, 25 ns Delay
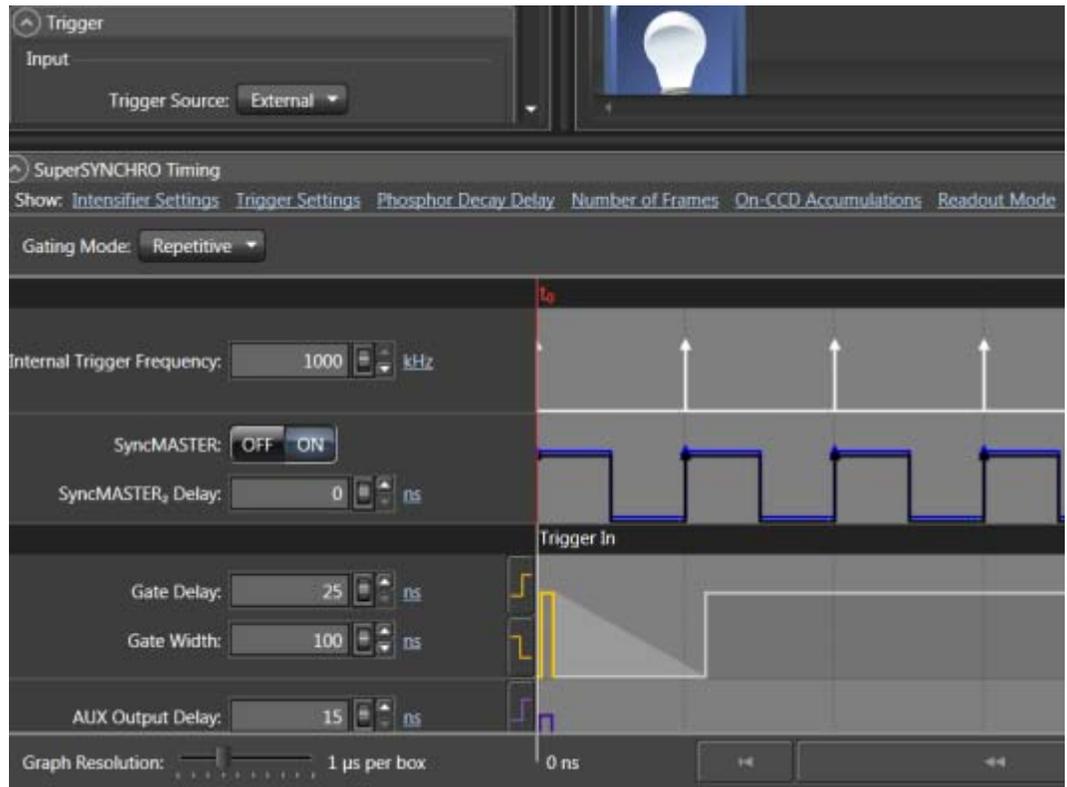
4411-0137_0082

Figure 6-22 shows the result of this experiment.

Figure 6-22: Single Shot Result: Fluorescence Spot, Width = 100 ns, Delay = 10 ns
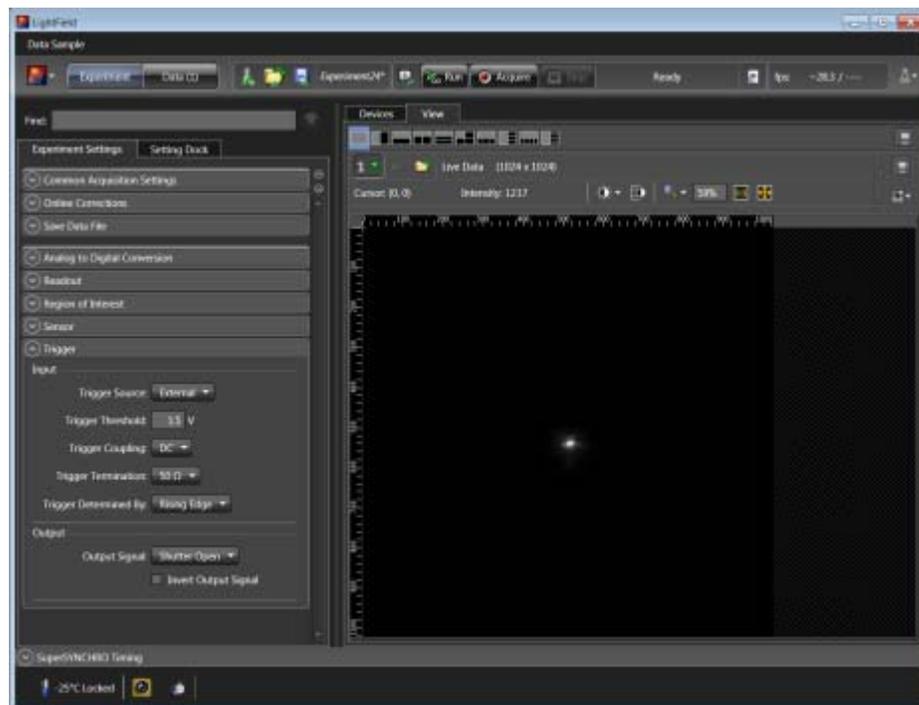
4411-0137_0083

Figure 6-23 shows the peak obtained by binning the entire region around the fluorescence spot in the vertical direction.

Figure 6-23: Single Shot Result: Fluorescence Spot, Width = 100 ns, Delay = 10 ns, Binned Vertically
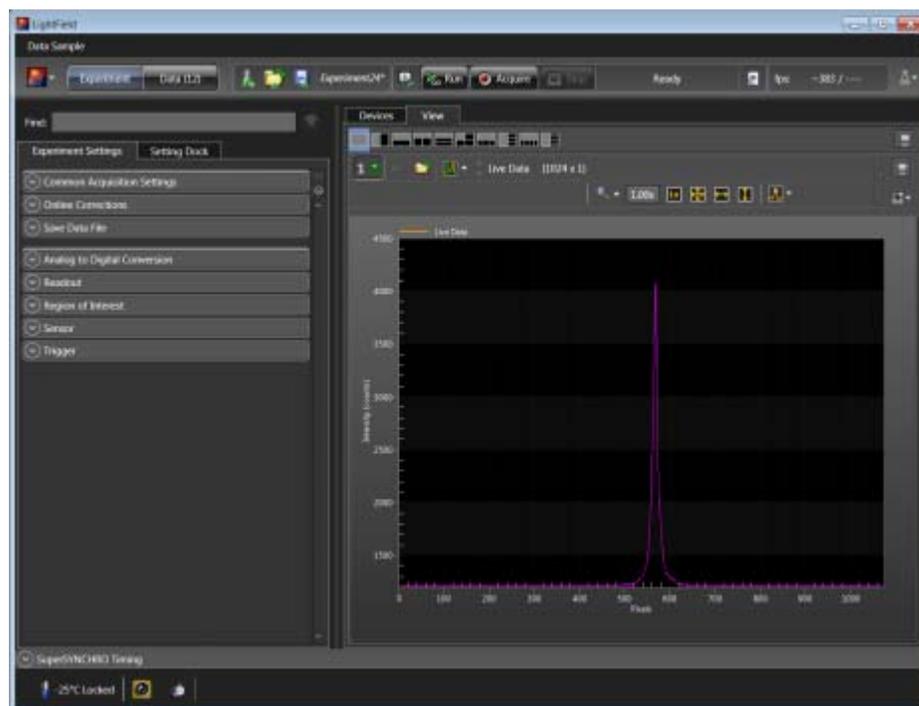
4411-0137_0084

6.5.3   Swept Gate Experiment [Variable Width, Variable Delay]

The procedure for conducting a Swept Gate experiment with variable width and variable delay is the same as that for conducting a Swept Gate experiment with fixed width and variable delay with the following parameter configuration changes:

- **Starting Gate Delay** value does not equal **Ending Gate Delay** value;
- **Starting Gate Width** value does not equal **Ending Gate Width** value.

Refer to Section 6.5.3, Swept Gate Experiment [Variable Width, Variable Delay], for additional information.

6.5.4   Static Gate Experiment [Fixed Width, Fixed Delay]

The procedure for conducting a Static Gate experiment is similar to that for conducting a Swept Gate experiment with the following parameter configuration changes:

- **Gate Mode**: **Repetitive**;
- **Gate Width** and **Gate Delay** must be entered on the **SuperSYNCHRO Timing** expander as shown in Figure 6-24.

Figure 6-24: Repetitive Gating Setup Dialog
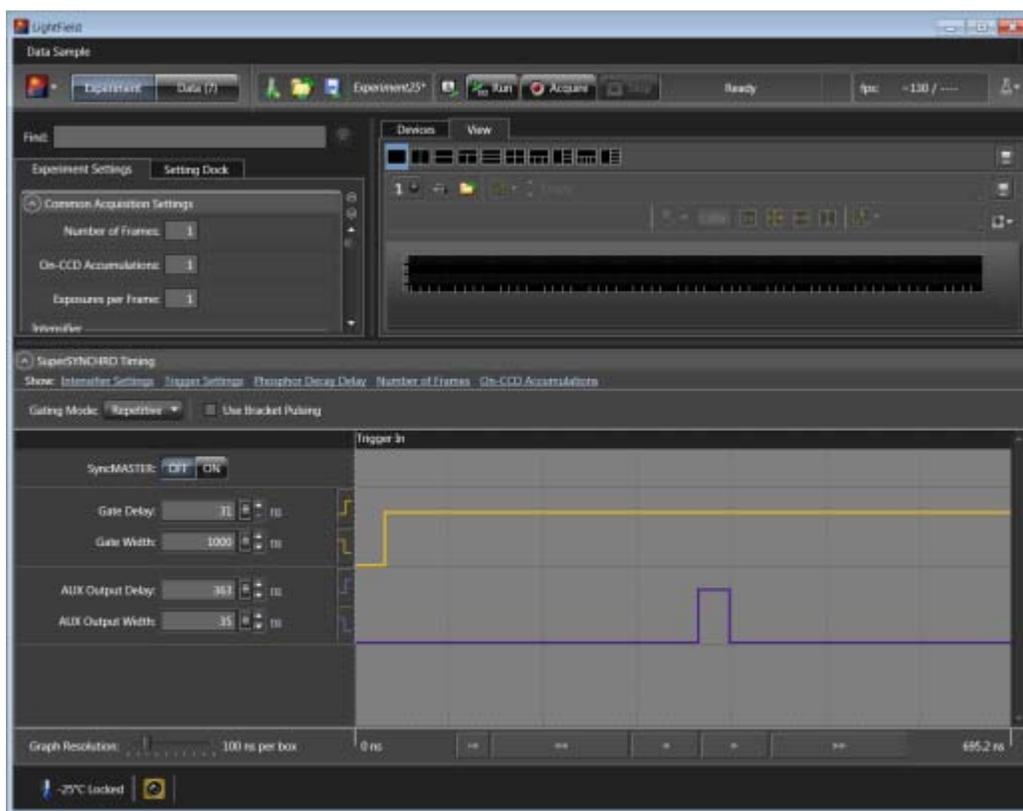
4411-0137_0085

Refer to Section 6.5.4, Static Gate Experiment [Fixed Width, Fixed Delay], for additional information.

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Chapter 7:   WinX and Gated Operation

This chapter discusses gated operation with the SuperSYNCHRO™ timing generator as well as aspects of PI-MAX4 operation that are not covered in Chapter 4, First Light.

Chapter 15, Tips and Tricks, should also be reviewed since it provides helpful information about how to achieve desired results when performing more complex measurements.

7.1   Gating

Gating provides electronic shutter action by controlling the photocathode bias, allowing the detection of low light level signals in the presence of interfering light sources of much greater energy. For instance, in combustion research, a pulsed laser probe is used to investigate the chemistry within a flame. Since the flame itself emits broadband light continuously, the integrated flame emission is much greater than the integrated signal resulting shortly after the laser probe (e.g., laser-induced fluorescence or Raman.) Fortunately, since the laser pulse is very short and the time at which it occurs is known, it is possible to gate for a few nanoseconds during the laser pulse, thus reducing the flame emission interference by approximately the measurement duty factor ratio.

Exposure time is the 'time space' from which charge integrating on the CCD will get summed into the reported data. Gate width is the time during which light will be detected by the intensifier, intensified, and applied to the CCD. Basically, the intensifier controls what the chip 'sees' during the exposure time.

For a signal to be detected, it must fall in a valid gate width during a valid exposure. Many gate pulses can be placed into one exposure at repetitive or sequential intervals because there is no temporal measure inside a given exposure [i.e., all incident signals are summed (integrated) into one value per pixel/super pixel inside a given exposure.]

Using currently available image intensifiers and gate pulse generators, optical gate times ≤ 4 ns FWHM (full width at half maximum) are possible. Since the control is electronic, the gate width can be made virtually as long as desired, allowing a wide range of experiment requirements to be satisfied in one instrument setup. Further, during UV measurements where the On:Off ratio is only 10^4:1, the PI-MAX4's MCP bracketing feature can be used to extend the On:Off ratio to 10^6:1.

7.2   Safety Precautions

When biased ON, intensified CCD cameras such as the PI-MAX4 can be permanently damaged if continuously exposed to light levels exceeding twice the A/D saturation level. It is **critical** that a camera **not** be operated under lighting conditions which may damage the intensifier.

Although intensified cameras operating in gated mode are less prone to damage from *background light*, they are at **significant risk** of damage from high-intensity light sources such as LASERs. High intensity sources can damage an intensifier before protection circuits have time to respond. Spot damage may result without the protection circuits acting at all.

If a sustained alarm indication occurs when the controller is turned on, immediately turn the **I.I.T.** switch on the back of the PI-MAX4 to the **OFF** position. Cover the camera's window, and only after the illumination level has been lowered to safe operating conditions can the **I.I.T.** switch be turned **ON**.

7.2.1   Intensifier Mode

The PI-MAX4 can operate in one of two intensifier modes:

- **Gate Mode**;
  The photocathode is biased on only for the time that each gate pulse is applied. As a result, the tolerance to room light is higher in gated operation, but the risk of damaging overload from intense light sources such as lasers remains. In fact, intense light sources in gated experiments can cause spot damage that would be undetected by the alarm circuit.

  NOTE: ─────────────────────────────────

  In order for gating to occur, the I.I.T. switch on the back of the PI-MAX4 must be in the **ON** position.

- **Safe Mode**.
  The photocathode is continuously biased OFF and the intensifier is as safe as it can be.

Within WinX applications, the intensifier mode is configured within the **Experiment Setup —> Main** screen.

7.2.2　Alarms

> **NOTE:**
>
> It is normal for an alarm to sound briefly when the system is
> initially turned on.

To reduce the risk of camera damage, the PI-MAX4 camera is equipped with an audible
alarm in the camera head, activated when the intensity of light falling on the image
intensifier exceeds a preset threshold. While the alarm is sounding, the photocathode is
disabled. Immediately toggle the **I.I.T.** switch (on the back of the PI-MAX4) to the **OFF**
position. Cover the camera window and only switch the **I.I.T.** switch to **ON** after the
illumination level has been lowered. If the alarm sounds continuously even when the
illumination level is adequately low, shut the system down and contact the factory for
guidance.

> ⚠ **CAUTION!**
>
> Discontinue operation and contact the factory at once if
> sporadic or continuous unwarranted alarms occur. They may
> indicate intensifier damage or another situation that requires
> immediate attention.

7.3　Timing Mode

In **Gate Mode**, the internal timing generator uses **Internal Sync** timing which initiates a
readout cycle following each internally-generated timing pulse sequence.[1]

Internal handshakes are used to prevent:

- A readout from being initiated when the timing generator is busy;
- Biasing the photocathode ON while a readout cycle is in progress.

The following camera parameters are automatically configured by WinX and cannot be
changed:

- **Exposure Time**: Set to 0;
- **Continuous Cleans**: disabled;
- **Shutter Control**: Disabled Opened.

> **NOTE:**
>
> These parameters may not be visible in some versions of the
> application software.

---

1. An internal timing generator pulse sequence consists of a Gate Start pulse, a Gate Stop pulse, and one or more
   Auxiliary pulses.

Refer to Table 7-1 for additional Internal Sync information when using Gated mode.

Table 7-1: Internal Sync Information for Gated Operation

Timing Mode	Shutter Control	Ext. Trigger Input
Controlled by Internal Timing Generator	Controlled by Internal Timing Generator	Trigger In BNC

> **NOTE:**
>
> The **Accumulations** and **Images** (or **Spectra**) parameters (WinView/32 or WinSpec/32 Acquisition Setup **Main** tab) determine how data will be processed. Integrating multiple events on the CCD really brings the power of the PI-MAX4 to bear on low-light gate-mode experiments. If the experiment allows, many pulses can be summed on the CCD with no pulse artifacts in the readout. The signal increases nearly linearly with the number of pulses (within limits imposed by the CCD.)

7.4 Micro-Channel Plate (MCP) Bracket Pulsing

The primary advantage gained from incorporating gating is that it allows temporal discrimination against background light. By allowing the photocathode to "see" only during the event of interest, very high background illumination levels can be tolerated without materially degrading experiment results. Limits for this technique are determined by the light leakage of the intensifier, which, although very good, is not without bounds.

- Within the visible spectrum, the on/off ratio of a typical Gen II Intensifier with just the photocathode gated is excellent, typically between 10^6 and 10^7. For most measurements, this ratio is more than adequate to guarantee that any signal reaching the CCD during intensifier Off times is too small to affect the data.

- However, when working with wavelengths below 350 nm, optical leakage through the photocathode to the UV-sensitive MCP occurs. At 200 nm, the on/off ratio is reduced to approximately 2×10^4. This is the dominant response of a Gen II image intensifier to UV photons when the photocathode is electrically off. At an On/Off ratio of 20,000, the ability of a camera with conventional photocathode (only) gating to perform certain kinds of measurements in the UV is adversely affected.

MCP bracket pulsing[1] keeps the MCP biased OFF except for an interval that brackets the timing of the photocathode gate as shown in Figure 7-1.

---

1. Bracket pulsing is not available for cameras having a filmless Gen III Intensifier. Gen III Intensifiers do not respond in the UV.

Figure 7-1: Timing Diagram: MCP Bracket Pulsing

For emitted photoelectrons to be accelerated in the MCP, the MCP must be biased ON. In conventional intensified cameras, the MCP is biased ON continuously. In PI-MAX4, however, when bracket pulsing is ON, the MCP is biased OFF until just before the photocathode is gated ON and is biased OFF shortly after the photocathode is biased OFF.

By bracket pulsing the MCP off (in addition to photocathode gating,) the on/off ratio of the Gen II PI-MAX4 in UV is improved by two to three orders of magnitude. The resulting UV ratio exceeds even the high levels normally achieved in the visible. Applications that benefit from this new approach include LIF and nanosecond pump-probe experiments.

NOTE:

Bracket pulsing does not help in the visible region. Under extremely low duty-factor conditions, the only remedy is to install an external shutter ahead of the camera.

7.4.1 Bracket Pulsing in LIF Measurements

Most experiments using laser-induced fluorescence to probe combustion flows are performed with UV probe/lasers. Atomic emission from flames also has significant UV content. If the flame is continuous, the UV background will also be continuous. Even where a flame is transient (e.g. internal combustion engine,) its lifetime can be many milliseconds, compared to the nanosecond time scale of the laser used. This background can be a million times as long. If the background is bright, then a UV on/off ratio of 20,000:1 will be overwhelmed by the duty cycle and will not be adequate for extracting a signal of 10^{-5}. In high dynamic range quantitative measurements, backgrounds must be kept to an absolute minimum. MCP bracket pulse gating dramatically improves the rejection of CW and even millisecond time-scale background.

An alternative to suppressing background for imaging has been the use of very narrow spectral bandpass filters. In the UV, these filters are expensive and they can have low transmission at their central wavelength. An additional filter is required for each wavelength to be imaged. The use of electronic temporal rejection of CW or quasi-CW background may make it unnecessary to use these filters, thus increasing the optical throughput, sensitivity, and quantitative precision of the measurement.

7.4.2   Bracket Pulsing in Nanosecond Pump Probe Experiments

Some nanosecond pump-probe experiments combine a nanosecond or faster pump with a flashlamp probe. The duration of the probe flash can be 10-50 μs and a gate is used to select the specific nanosecond-scale time slice to be observed within the much longer probe flash. In these absorbance experiments, accurate measurement of absorbance values depends critically on the lack of stray light contamination, particularly at moderate to high optical density levels. Selecting a 5 ns time window out of a 10 μs pulse is already one part in 2,000. If UV leakage gives an on/off ratio of only 20,000:1, contamination could be 10% of higher. This would limit the optical density to 1.0, and it could make linear quantitation difficult beyond 0.1 OD.

MCP bracket pulse gating can substantially improve the on/off ratio in such an experiment. Even with a 1 μs MCP pulse, the rejection of flash-lamp leakage can add more than an order of magnitude of range, to 2.0 OD.

7.4.3   Limitations of Bracket Pulse Gating

MCP bracket pulse gating is most useful in rejecting background that lasts microseconds up to CW. Fast transient backgrounds can be in the form of stray laser light scattering (Raleigh, MIE, Raman,) or unwanted fast fluorescence. Because these usually fall below the MCP bracket pulsing 35 ns delay restriction, these measurements cannot be improved much by MCP bracket pulsing in the PI-MAX4.

Electrically, gating the MCP will only reduce leakage at wavelengths where the MCP has photoelectric response (primarily in the UV.) Thus, for visible and NIR wavelengths where leakage is primarily optical, the improvement will be minimal (although the on/off ratio is already very good in these regions.) Note that in some spectroscopic applications, visible leakage may appear to be reduced by MCP pulsing. This is because the second order UV spectrum overlays the first order visible spectrum in a grating spectrograph. MCP pulsing can eliminate unwanted sensitivity to CW or quasi-CW second order UV, causing the apparent improvement.

Also, keep in mind that MCP bracket pulsing adds 10 ns delay to the photocathode gating. Even though the bracket timing is controlled automatically by the software, in an experiment where it is necessary to delay the arrival of the laser pulse at the sample, this will mean inserting an additional delay of 10 ns (minimum gate delay = ~25 ns, with bracket = 35 ns,) to accomplish coincidence at the camera. MCP bracketing should only be used in experiments where it is going to make a difference.

Also, MCP bracket gating limits the repetition rate to 6.25 kHz, without it the gate repetition rate can be up to 1 MHz (more with option boards.) This is not a significant limitation in most cases. Note that with a 10 ns gate at 6.25 kHz, the on/off ratio = 16,000, close to the non-bracket value.

Note that background light need not be the limiting factor in measurements where MCP bracket pulsing is unable to provide the required degree of rejection. In such measurements, the option remains of installing an external shutter ahead of the PI-MAX4.

7.4.4 Impact of Bracket Pulsing on Delay

If operating in the UV when bracket pulsing is activated (Gen II Intensifier only,) the MCP gate automatically brackets the photocathode gate pulse to further enhance the on/off ratio. There is, however, a limitation of bracket pulsing that can complicate the coincidence of the signal and gate at the camera. Because MCP bracket gating is slower than photocathode gating (35 ns is required to gate the MCP on and another 1 µs to gate the MCP off at the end of the photocathode gate.) As a result, MCP bracket pulsing should not be used in experiments where the delay between the trigger and the photocathode gate is less than 35 ns.

7.4.5 Configuration

MCP Bracket pulse implementation is enabled by selecting **Bracket Pulsing ON** from within the host software. Figure 7-2 illustrates the timing diagram for bracket pulsing.

> **NOTE:**
>
> Because Gen III Intensifiers do not respond in the UV, bracket pulsing is not available for these intensifiers.

Figure 7-2: Timing Diagram: MCP Bracket Pulsing
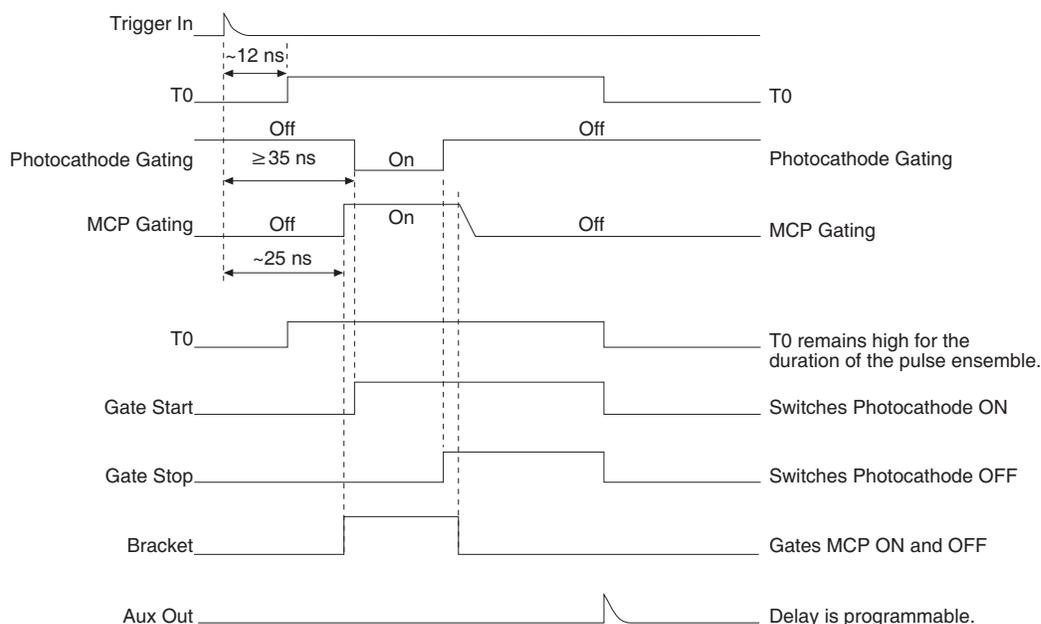
4411-0137_0048

As shown in Figure 7-2, the insertion delay between **Trigger In** and **T$_0$** is approximately 12 ns, and the insertion delay between **Trigger In** and **Photocathode Gating** is 35 ns.

> **NOTE:**
>
> The minimum delay between **Trigger In** and **Photocathode Gating** in bracket mode is 35 ns in order to allow the MCP to achieve "full gain" before the photocathode is gated on.

7.5   Experiments

Figure 7-3illustrates a breakdown of the types of experiments that can be performed with a PI-MAX4 camera.

Figure 7-3:   Typical PI-MAX4 Experiments

4411-0137_0049

Most gated measurements that can be performed with a PI-MAX4 will fall in one of the following categories:

- **Static Gate**

    This type of experiment may also be referred to as "Repetitive-Continuous." There is a repetitive trigger, and the Gate Width and Gate Delay are fixed. Some variable in the experiment such as pressure, concentration, wavelength, or temperature, are varied.

- **Swept Gate**

    In this type of experiment, Gate Width and/or Gate Delay may be varied.

    — Repetitive-Sequential 1

    The Trigger is repetitive, Gate Width is fixed, and Delay is varied over the course of the measurement. The result of the experiment is a plot of intensity vs. time, such as might be obtained with a sampling oscilloscope. This technique is used to measure lifetime decays.

    — Repetitive-Sequential 2

    The Trigger is repetitive and Gate Width and Delay are varied over the course of the measurement. Gate Width and Delay can be incremented in a linear fashion or in an exponential fashion. Increasing the Gate Width is useful for trying to find fine detail in a weak decaying signal. If you choose linear, you have to take a lot more points. Exponential lets you take data points closer together where the signal is changing rapidly and further apart where the signal is changing slowly.

- **Single Shot**
  A single shot experiment is one where there is only one chance to obtain the data. Any experiment that can not be repeated more often than once a minute, such as high power lasers and explosives, is considered a single shot. You have to catch the trigger when it comes. Prior to the event, the CCD runs in continuous cleans mode. You don't have the luxury of having the CCD just sitting there doing nothing because the CCD will be accumulating dark current. When the trigger arrives, the intensifier gates, the continuous cleans stop, and the array is read out with a minimum of dark current. Pre-Trigger can be helpful if available.

Refer to the following sections for information about conducting the indicated experiments:

- Section 7.5.1, Swept Gate Experiment [Fixed Width, Variable Delay];
- Section 7.5.2, Single Shot Experiment;
- Section 7.5.3, Swept Gate Experiment [Variable Width, Variable Delay];
- Section 7.5.4, Static Gate Experiment [Fixed Width, Fixed Delay].

7.5.1   Swept Gate Experiment [Fixed Width, Variable Delay]

This experiment is an attempt to time-resolve a Xenon light flash from a commercially available strobe light.

7.5.1.1   Experiment Supplies the Master Clock

Since the strobe does not have a "pre-trigger" out, an electrical trigger is generated by using a photodiode. Output from the photodiode is connected to the **Trigger In** BNC on the PI-MAX4.

Perform the following procedure to time-resolve a Xenon light flash from a commercially available strobe light:

1. Setup all equipment as illustrated in Figure 7-4. Timing diagrams are also provided for reference.

NOTE:

This procedure uses the experiment as the Master Clock. See Figure 7-4 for hardware connection information.

Figure 7-4:   Block/Timing Diagram: Swept Gate Experiment

* Level changes for T0 depend on the pulse sequence(s) defined by the user.
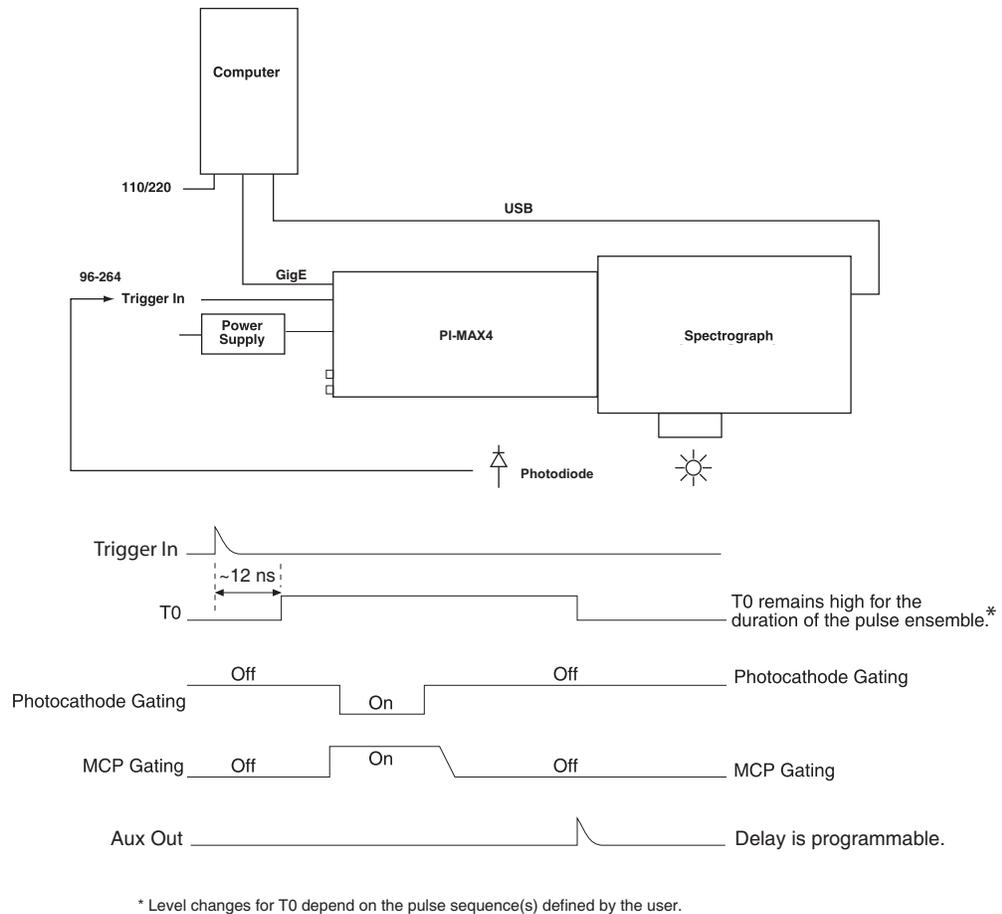
4411-0137_0050

2. Turn on all equipment and launch the WinX application software (version 2.5.25 or greater.)

3. Open the **Setup —> Hardware —> Hardware Setup** dialog. The Hardware Setup dialog should resemble that shown in Figure 7-5 which shows the setup for a KAI 1024x1024 interline camera.

Figure 7-5:   Typical Hardware Setup Dialog
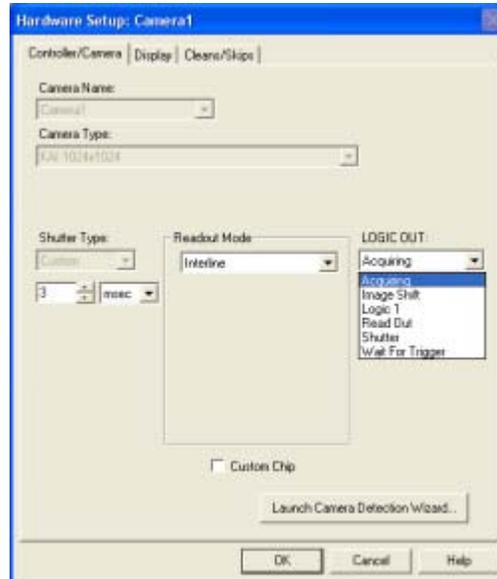
4411-0137_0023

4. Click on the **Cleans/Skips** tab.

5. Click the **Load Default Values** button.

6. Click **OK** to save the configuration information and dismiss the **Hardware Setup** dialog.

7. From the menu bar, select **Setup —> Detector Temperature**.

8. Within the **Target Temperature** field, enter the desired temperature.

9. Clicking **Set Temp** followed by **OK**.

📖 REFERENCES: ⎯⎯⎯⎯⎯⎯⎯⎯⎯⎯⎯

For additional information, refer to the WinView/32 or WinSpec/32 User's Manual as needed.

10. If using a spectrograph, configure the spectrograph properties by using the menu items on the **Spectrograph** menu (WinSpec/32 only.)

> **NOTE:** ───────────────────────────────
>
> If the spectrograph being used has not yet been installed, click **Install/Remove Spectrograph** to install the hardware prior to configuring any parameters.

Figure 7-6 illustrates the general sequence required to install an Acton 300I spectrograph using WinSpec/32. If installing a different spectrograph, select it from the list of Supported Spectrographs during step 2.

Figure 7-6:   Typical WinSpec/32 Installation Sequence: Acton 300I Spectrograph
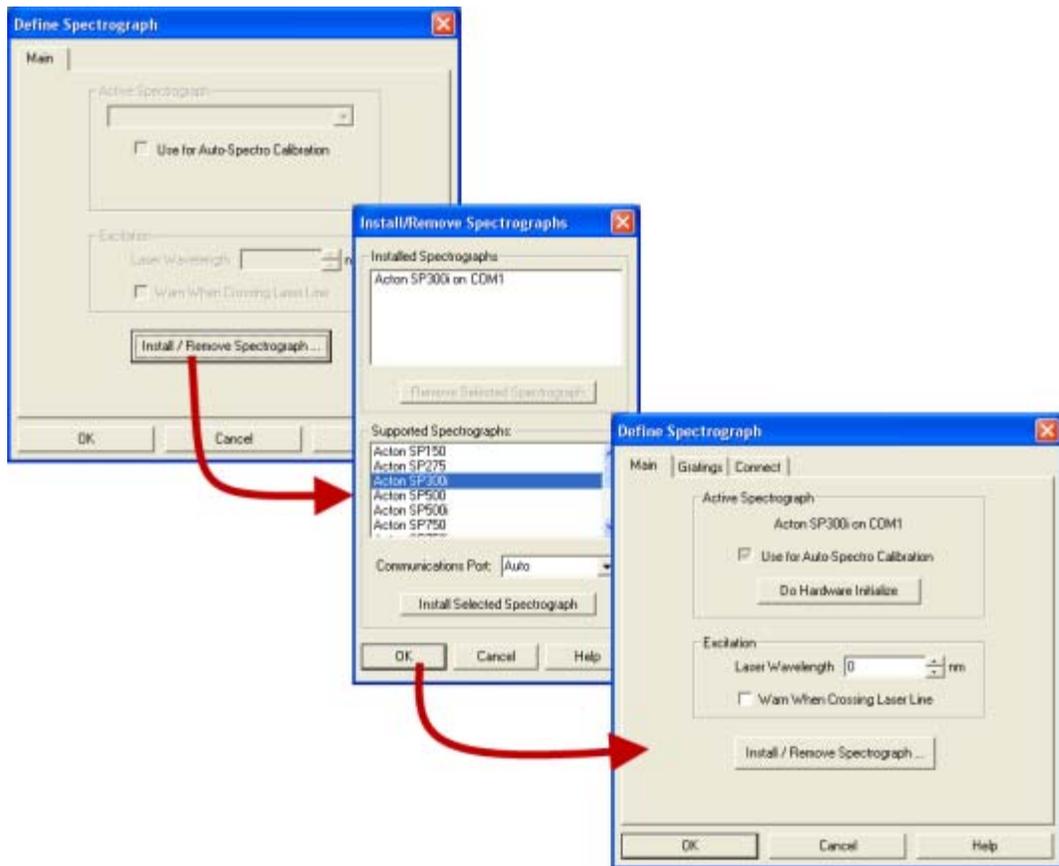
4411-0137_0051

11. After the spectrograph and been installed and configured, move the grating to the desired wavelength. See Figure 7-7.

Figure 7-7:   Typical Move Spectrograph Dialog

4411-0137_0052

12. Verify that the camera is operating and is properly focused by running it in **Internal Trigger** mode.

Perform the following procedure to run in Internal Trigger mode to verify camera focus:

a. From the pull-down menu, select **Experiment Setup**. If necessary, click on the **Main** tab. See Figure 7-8.

Figure 7-8:   Typical Experiment Setup Dialog: Main Tab
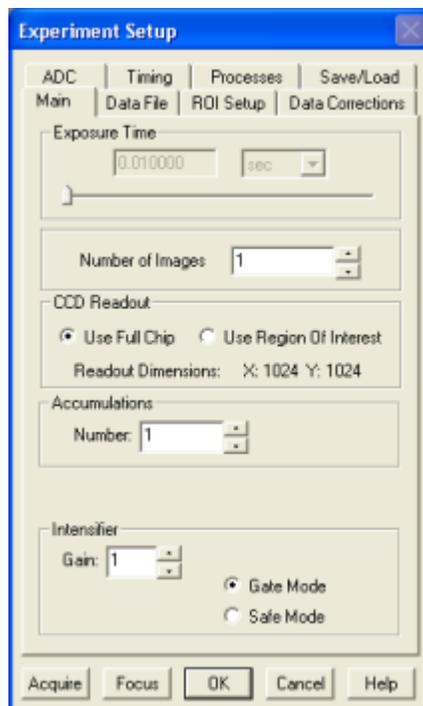
4411-0137_0013

    b. Within the **Intensifier** section, configure the following parameters:

- Select **Gate Mode** [radio button];
- **Gain**: Between 0 and 100.

    Configure MCP Gain for between 0 and 100.

    c. Click the **Timing** tab, and configure the following parameters:

- **Fast Mode** [radio button].

    See Figure 7-9.

Figure 7-9:   Typical Experiment Setup Dialog: Timing Tab
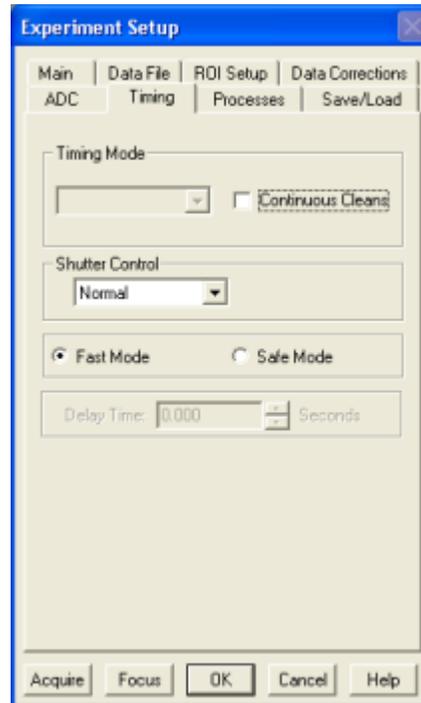
4411-0137_0053

    d. Click the **ADC** tab, and configure the following parameters:

      • **Rate**: Configure an appropriate rate from the pull-down menu.

Figure 7-10: Typical Experiment Setup Dialog: ADC Tab
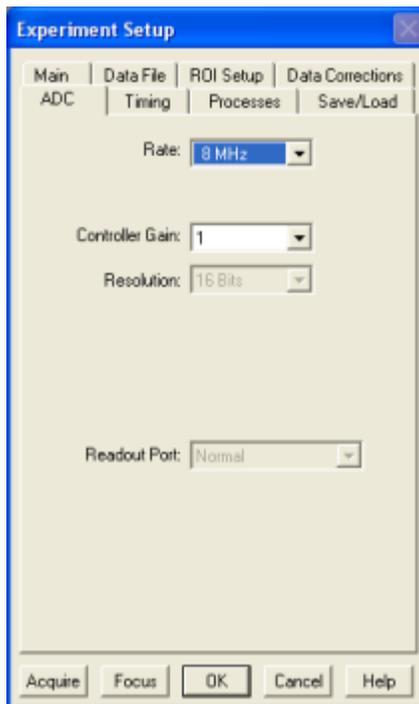
4411-0137_0014

    e. Click the **ROI Setup** tab, and configure parameters for the appropriate ROI.
See Figure 7-11.

Figure 7-11: Typical Experiment Setup Dialog: ROI Tab
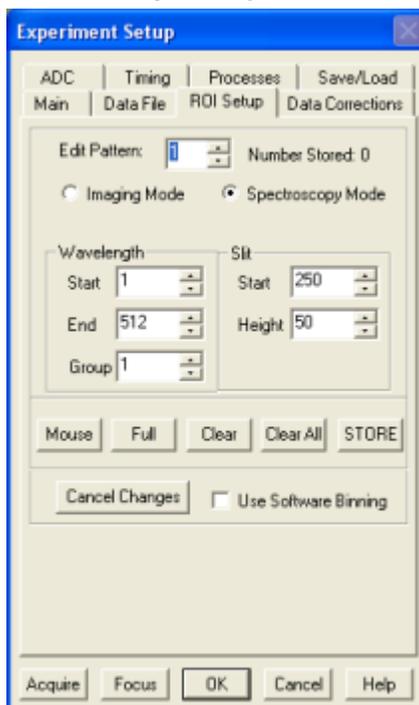
4411-0137_0054

f. Click **OK** to save all **Experiment Setup** configuration information and dismiss the dialog.

g. From the **Setup** pull-down menu, select **Pulsers**.

The **Pulsers** dialog is displayed, similar to that shown in Figure 7-12.

Figure 7-12: Typical WinX Pulsers Dialog
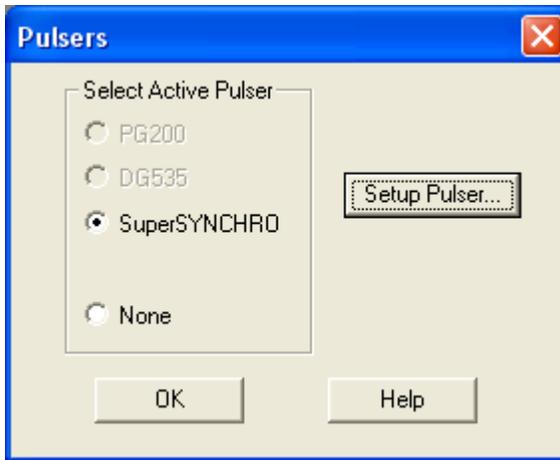
4411-0137_0009

h. Select the **SuperSYNCHRO** radio button, and then click on the **Setup Pulser…** button.

The **SuperSYNCHRO** dialog is displayed, as shown in Figure 7-13.

Figure 7-13: Typical SuperSYNCHRO Dialog: Trigger In Tab
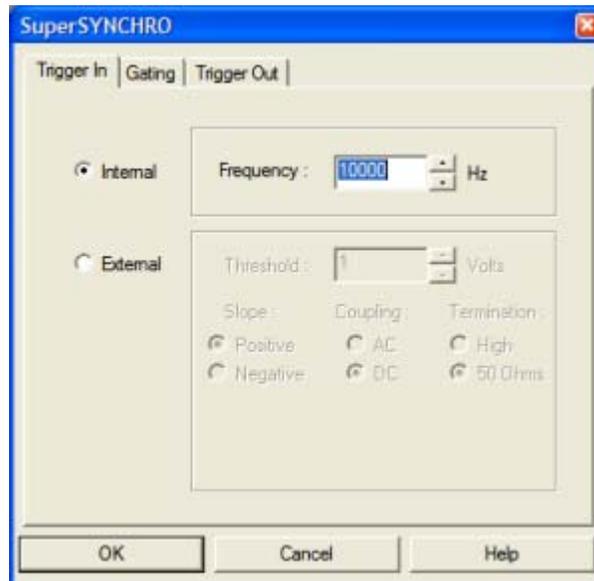
4411-0137_0010

i. If not already selected, select the **Internal** radio button.

j. Configure the desired **Frequency**, in Hz.

k. Click **OK** to save the configuration settings and dismiss the **SuperSYNCHRO** dialog.

l. Click **OK** to save the configuration settings and dismiss the **Pulsers** dialog.

m. Verify the ambient light level is low. Adjust the light level as required.

    n. Click on **Focus**.

- If **Readout Mode** has been configured to **Use Region of Interest**, data acquisition will immediately begin.
- If, however, **Readout Mode** has been configured to **Use Full Chip**, the system will display a pop-up dialog asking if this setting should be changed to **Use Region of Interest** before entering focus mode. Click **Yes** and the camera will momentarily begin acquiring data.

    o. Once it has been verified that the camera is operating properly and is in focus, halt data acquisition.

    p. Proceed configuring the system for the desired experiment.

13. Perform the following procedure to configure **Pulsers** as required:

    a. From the **Setup** pull-down menu, select **Pulsers**.

        The **Pulsers** dialog is displayed, similar to that shown in Figure 7-14.

Figure 7-14: Typical WinX Pulsers Dialog
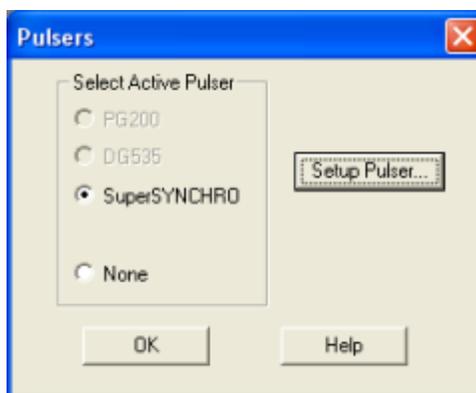
4411-0137_0009

    b. Select the **SuperSYNCHRO** radio button, and then click on the **Setup Pulser…** button. The **SuperSYNCHRO** dialog is displayed, as shown in Figure 7-15.

Figure 7-15: Typical SuperSYNCHRO Dialog: Trigger In Tab
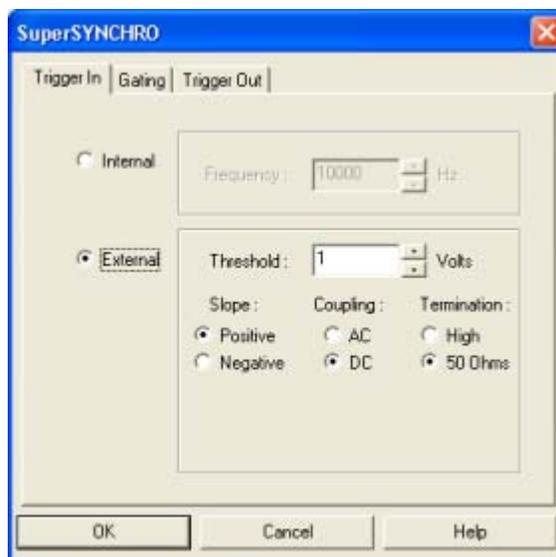
4411-0137_0010

Click on the **External** radio button and modify the configuration as necessary.

    c. Click on the **Gating** tab to configure the following parameters:

* **Mode**: **Sequential** [radio button];
* **Bracket Pulsing**: **OFF** [available for Gen II Intensifiers ONLY].

    See Figure 7-16.

Figure 7-16: Typical SuperSYNCHRO Dialog: Gating Tab

AVAILABLE ONLY FOR
GEN II INTENSIFIERS
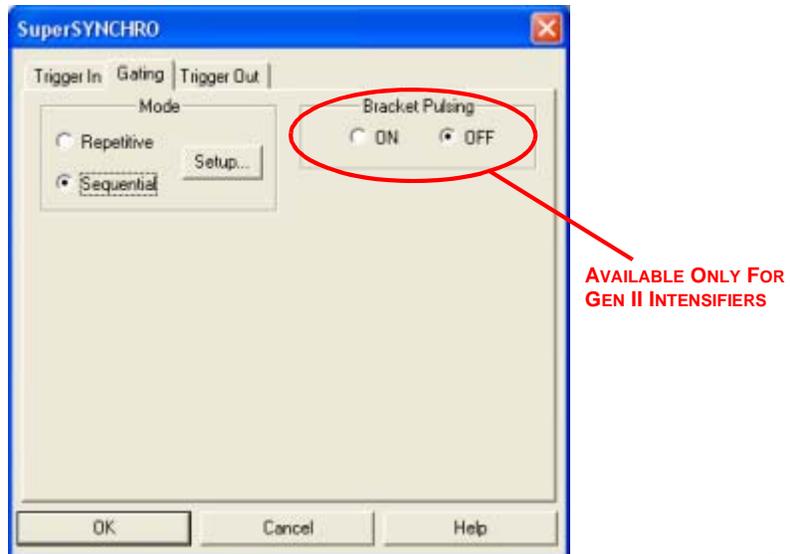
4411-0137_0056

    d. Click the **Setup …** button to display the **Sequential Gating Setup** dialog similar to that shown in Figure 7-17.

Figure 7-17: Typical Sequential Gating Setup Dialog
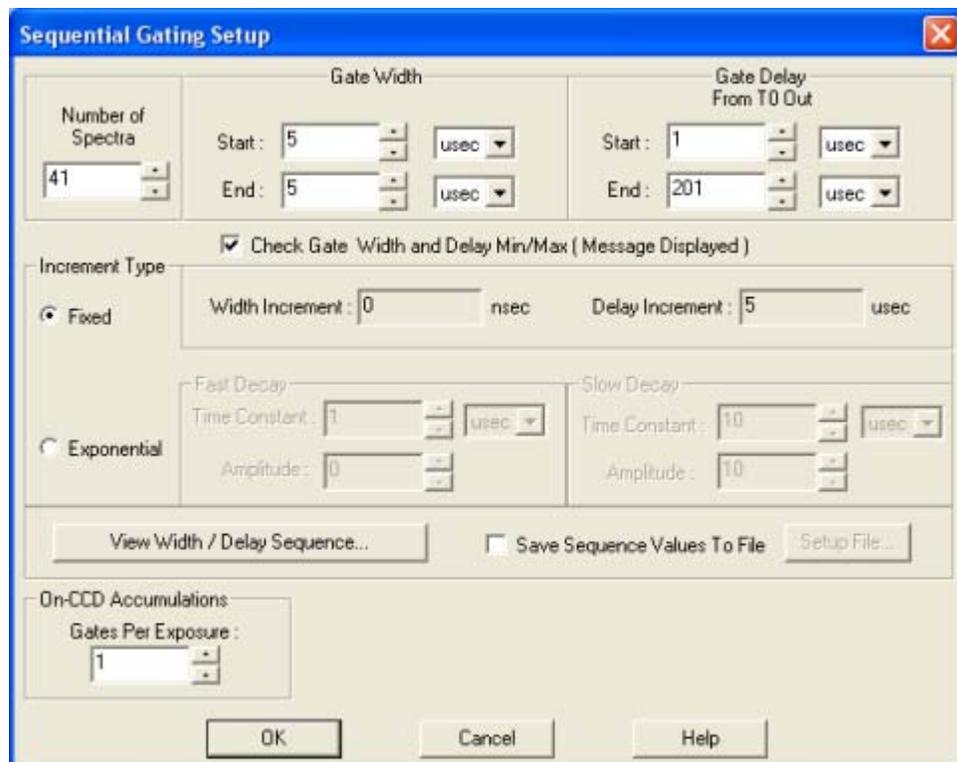
4411-0137_0057

Configure the following **Sequential Gating** parameters:

- **Number of Spectra** to be acquired (e.g., 41);
- **Increment Type**: **Fixed** [radio button]
- **Gate Width Start**

  This is the desired initial Gate Width.

  Both numeric value (e.g., **5**,) and an associated unit (e.g., **µsec**,) must be configured.

- **Gate Width End**

  This is the desired ending Gate Width.

  Both numeric value (e.g., **5**,) and an associated unit (e.g., **µsec**,) must be configured.

NOTE: ─────────────────────────────

In this example, a fixed gate width experiment is being configured. Therefore, the starting and ending Gate Widths will be the same.

───

- **Gate Delay Start**

  This is the desired initial Gate Delay.

  Both numeric value (e.g., **1**,) and an associated unit (e.g., **µsec**,) must be configured.

- **Gate Delay End**

  This is the desired ending Gate Delay.

  Both numeric value (e.g., **201**,) and an associated unit (e.g., **µsec**,) must be configured.

- **On-CCD Accumulations: Gates Per Exposure**: (e.g., **1**.)

NOTE: ─────────────────────────────

To examine the gate delay for each acquired spectra, click on **View Width/Delay Sequence**. See Figure 7-18.

Click **Close** when done.

───

Figure 7-18: Typical View Width/Delay Sequence Dialog
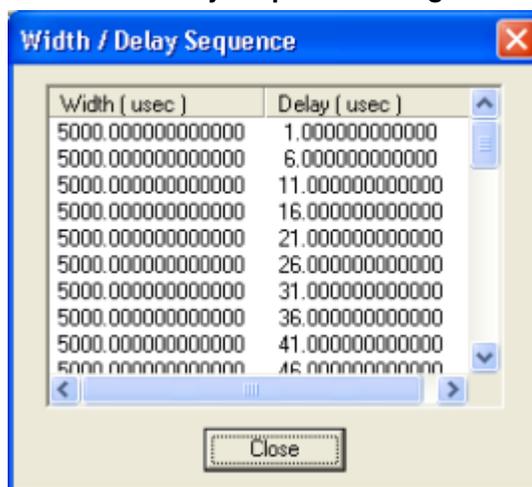
    e. Click on the **Trigger Out** tab to configure the following parameters:

- **SyncMASTER Trigger Out**

  When **Enabled** (i.e., checked,) the frequency of the **SyncMASTER1** output is the same as the frequency of the **Trigger In** signal. Refer to step 13.b on page 135.

- **SyncMASTER2 Delay from SyncMASTER1**: measured in μsec.

  The output of the **SyncMASTER2** signal is identical to that of the **SyncMASTER1** output. However, a delay, in microseconds, may be configured so that the leading and trailing edges **SyncMASTER2** will occur a specified time AFTER the corresponding edges of **SyncMASTER1**.

- **Auxiliary** Parameters

  When using the **Aux Out** signal to trigger an external piece of equipment, configure the following parameters:

  — Width

      Specifies the width of the desired **Aux Out** trigger pulse. This will vary depending on the specific equipment being controlled.

  — Delay

      Specifies the delay between the start of **SyncMASTER1** and the start of the **Aux Out** trigger pulse.

  See Figure 7-19.

Figure 7-19: Typical SuperSYNCHRO Dialog: Trigger Out Tab

4411-0137_0059

    f. Click **OK** to configure all SuperSYNCHRO parameters and dismiss the dialog.

14. Configure experiment parameters from the **Experiment Setup** dialog.

    a. Click on the **Timing** tab and configure the timing as shown in Figure 7-20.

Figure 7-20: Experiment Setup: Timing Tab
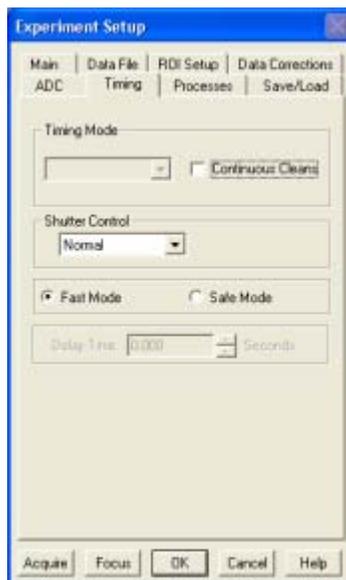
4411-0137_0053

    b. Click on the **Main** tab, select **Gate Mode**, and enter the desired **Intensifier Gain**. The number of spectra is automatically updated depending on the number entered on the **Sequential Gating Setup** dialog. See Figure 7-21.

Figure 7-21: Experiment Setup: Main Tab
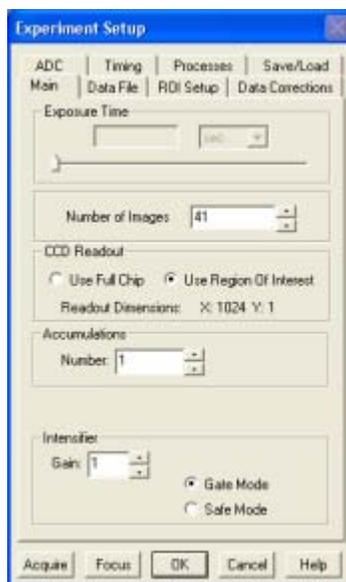
4411-0137_0060

📖 **NOTE:**

In **Gate Mode**, the photocathode is biased on only for the time that each gate pulse is applied. This limits the risk of damage resulting from room light. However, there is a risk of damaging overload from intense light sources such as lasers.

15. After verifying all connections and equipment readiness, click on **Acquire** to begin acquiring spectra or images.

16. Figure 7-22 illustrates a 3-D graph obtained for a **Sequential-Repetitive** experiment with Fixed Width and Variable Delay. See Figure 7-15 through Figure 7-18 for configuration settings.

Figure 7-22: Typical Experiment Results Shown in 3-D
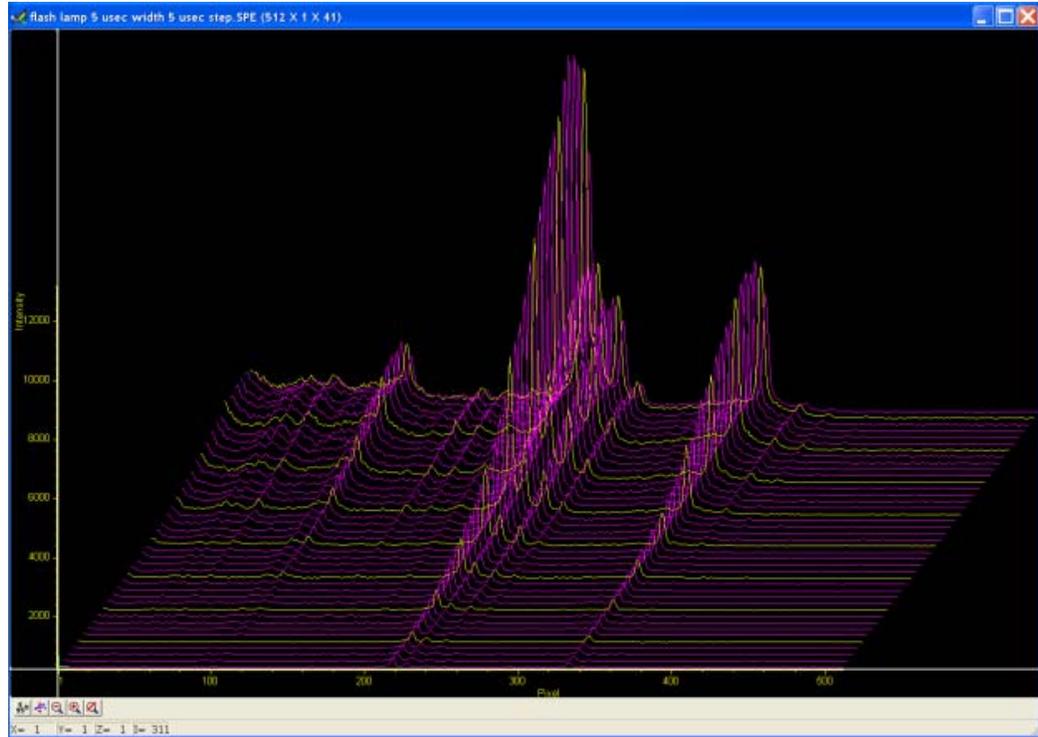
4411-0137_0061

7.5.1.2 *SyncMASTER1 Supplies the Master Clock*

When using a light source that has a **Trigger In**, the PI-MAX4 SyncMASTER function can be used as the Master clock. The setup procedure is similar that described in Section 7.5.1.1, Experiment Supplies the Master Clock, with the following changes:

- **Internal Trigger** is selected;
- **SyncMASTER** is enabled;
- A cable is required between the PI-MAX4 AUX I/O cable SyncMASTER1 BNC and the light source (i.e., experiment,) for triggering the event. See Figure 7-23

Figure 7-23: Block Diagram: SyncMASTER1 as Master Clock
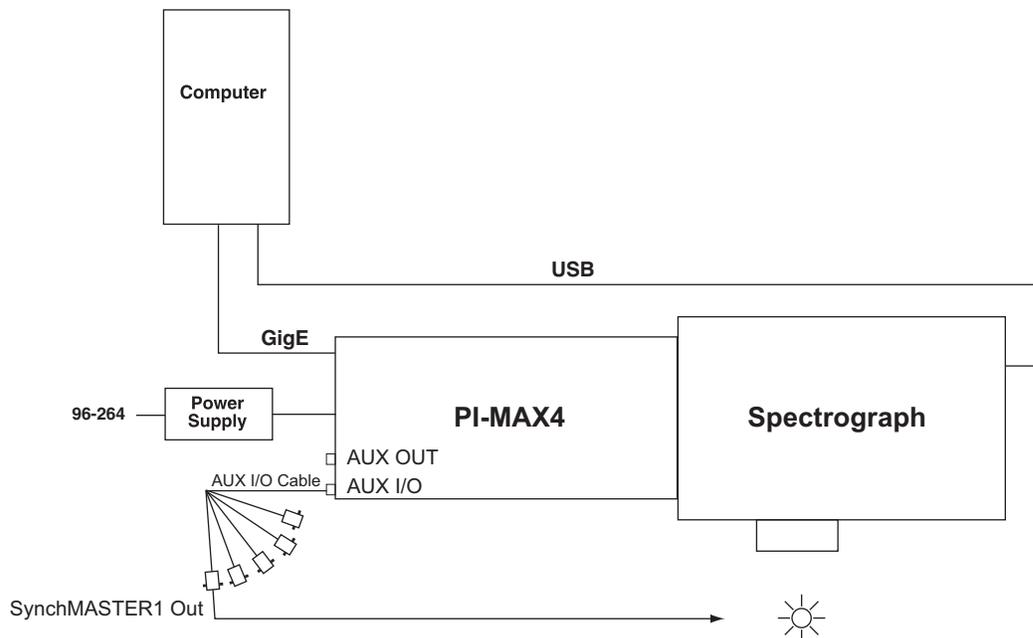
4411-0137_0062

Figure 7-24 illustrates the timing diagram for this experiment configuration.

Figure 7-24: Timing Diagram: SyncMASTER1 as Master Clock
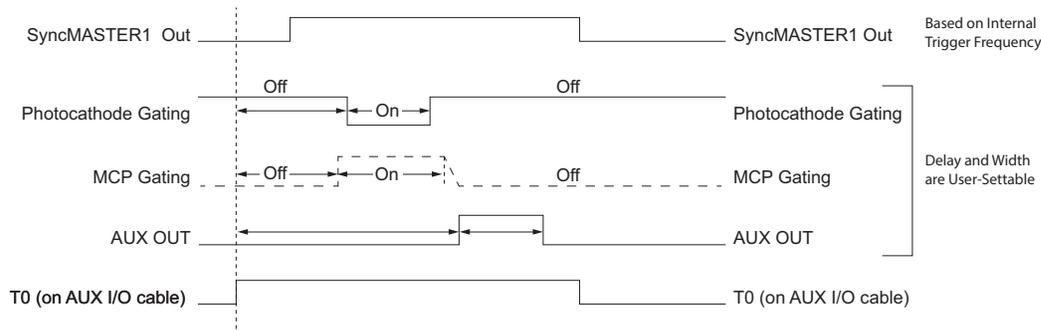
4411-0137_0063

7.5.2   Single Shot Experiment

A single shot experiment offers only one chance to capture an event. As with any gated experiment, the time budget of the experiment is critical. If there is no pre-trigger from the experiment, a photodiode can be used to generate an electrical trigger from the laser light. In this situation, light has to be delayed by optical means (e.g., fiber-optic cable or mirror reflections,) to allow sufficient time for the electronics to be activated after having received the trigger. Another important thing to note in single shot experiments is that the CCD is operating in **Continuous Cleans** mode so that there is no dark charge accumulation while it waits for the trigger.

This experiment is an attempt to capture a 60 ns fluorescence generated by a single shot laser. The time budget of the experiment is detailed in Table 7-2. This information is important in order to choose the correct length fiber optic cable.

Table 7-2:   Single Shot Experiment Time Budget

Delay Source	Delay (ns)	Total Delay (ns)	Fiber Optic Cable Length
Photodiode (light -> TTL pulse)	2	30	A minimum of 21 ft of fiber optic cable is required.
Photodiode -> PI-MAX4 (2 ft BNC cable)	3		
PI-MAX4	25		

In this experiment, cable lengths are kept to a minimum so that the length of the fiber optic cable required may also be minimized.

Figure 7-25 provides a block diagram of the hardware setup for a single shot experiment.

Figure 7-25: Block Diagram: Single Shot Experiment

4411-0137_0064
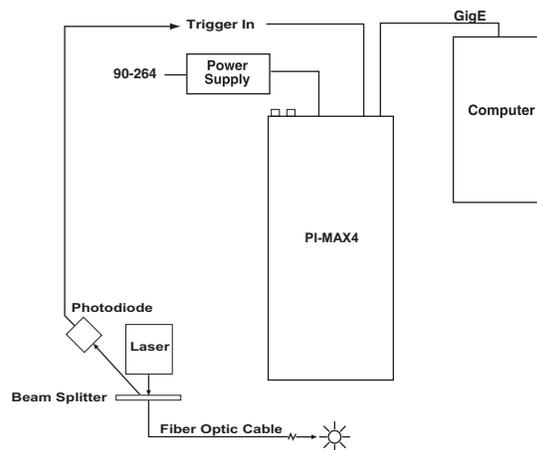
Once the equipment has been set up, default values for **Cleans/Skips** are configured. See Figure 7-26.

NOTE:

> If the CCD has to wait more than a few seconds for an external trigger, it is advisable to increase the number of cleans.

Figure 7-26: Hardware Setup Dialog: Cleans/Skips Tab
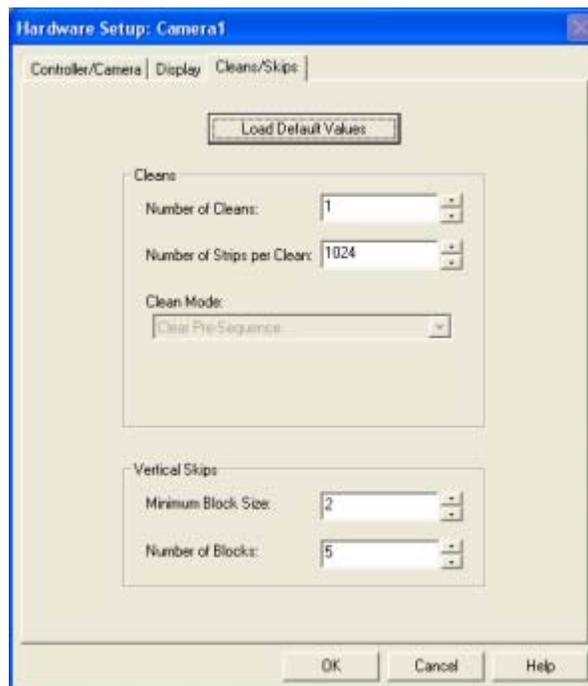
4411-0137_0065

The sequence of operations is similar to that for Sequential experiments. After focusing the camera on the fluorescing sample, the camera is configured for **Gate** mode and an appropriate **Gain** is configured. See Figure 7-27.

Figure 7-27: Experiment Setup Dialog: Main Tab
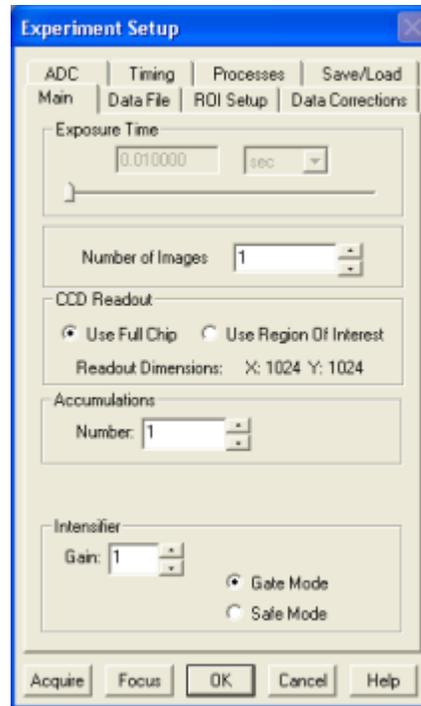
4411-0137_0013

Gate Width and **Gate Delay** should be configured so that the intensifier is gated **ON** during the entire event. For example, in this case the event is a 60 ns fluorescence. See Figure 7-28.

Figure 7-28: Typical Repetitive Gating Setup Dialog
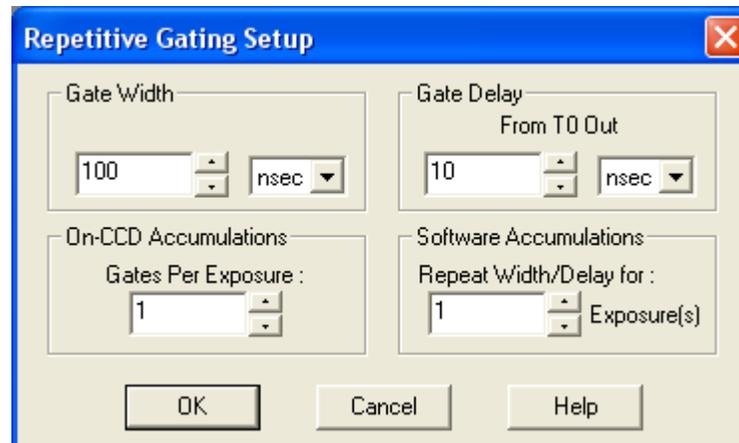
4411-0137_0066

Figure 7-29 shows the result of this experiment.

Figure 7-29: Single Shot Result: Fluorescence Spot, Width = 100 ns, Delay = 10 ns
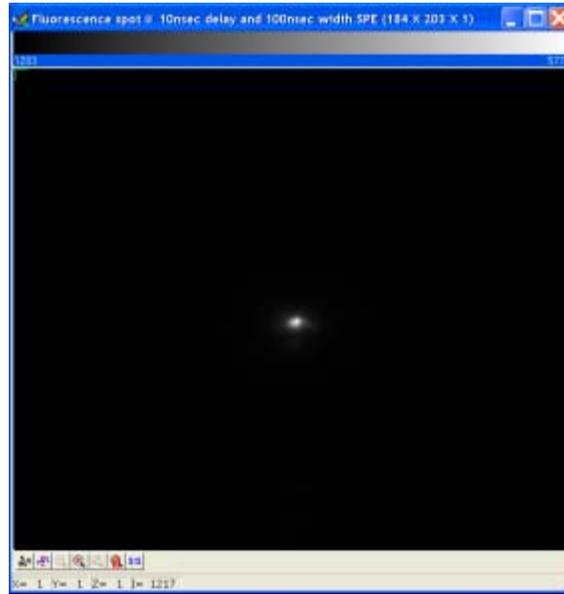
4411-0137_0067

Figure 7-30 shows the peak obtained by binning the entire region around the fluorescence spot in the vertical direction.

Figure 7-30: Single Shot Result: Fluorescence Spot, Width = 100 ns, Delay = 10 ns, Binned Vertically
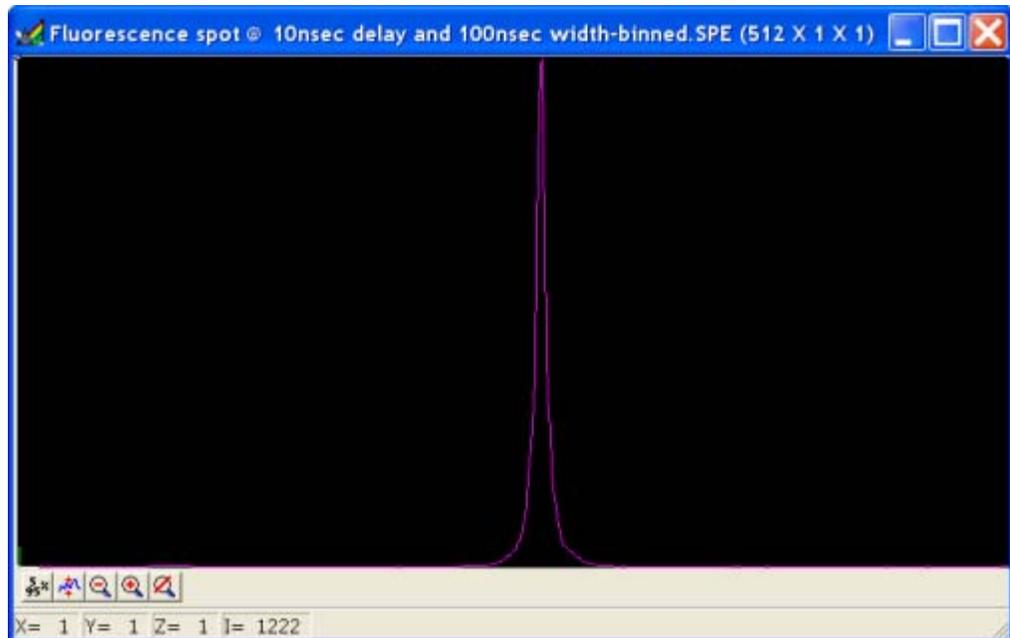
4411-0137_0068

7.5.3 Swept Gate Experiment [Variable Width, Variable Delay]

The procedure for conducting a Swept Gate experiment with variable width and variable delay is the same as that for conducting a Swept Gate experiment with fixed width and variable delay with the following parameter configuration changes:

- **Gate Delay Start** value does not equal **Gate Delay End** value;
- **Gate Width Start** value does not equal **Gate Width End** value.

Refer to Section 7.5.3, Swept Gate Experiment [Variable Width, Variable Delay], for additional information.

7.5.4 Static Gate Experiment [Fixed Width, Fixed Delay]

The procedure for conducting a Static Gate experiment is similar to that for conducting a Swept Gate experiment with the following parameter configuration changes:

- **Gate Mode**: **Repetitive**;
- **Gate Width** and **Gate Delay** must be configured using the **Repetitive Gating Setup** dialog as shown in Figure 7-31.

Figure 7-31: Repetitive Gating Setup Dialog
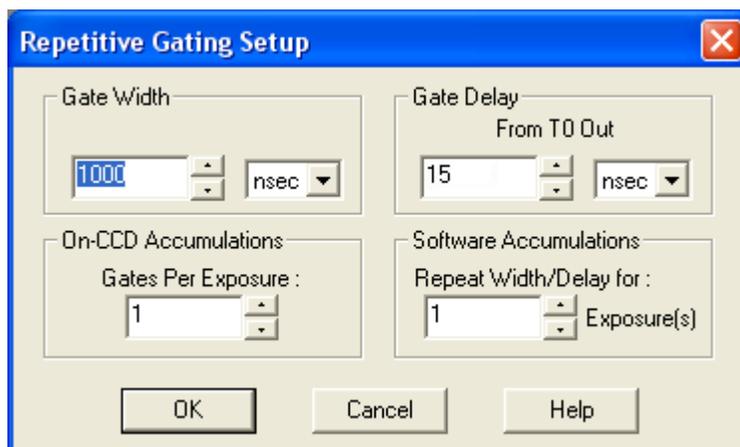
4411-0137_0069

Refer to Section 7.5.4, Static Gate Experiment [Fixed Width, Fixed Delay], for additional information.

Chapter 8: Timing Generator

This chapter describes the internal timing generator for the PI-MAX4.

8.1 Pulse Set

A Pulse Set comprises the following signals:

- MCP_GATE;
- START;
- STOP;
- AUX1;
- SyncMASTER.

START and STOP define the photocathode gate pulse. See Figure 8-1.

NOTE:

MCP GATE, START, and STOP are not visible to the user and are included for informational purposes only.

Figure 8-1: Timing Diagram: Pulse Set
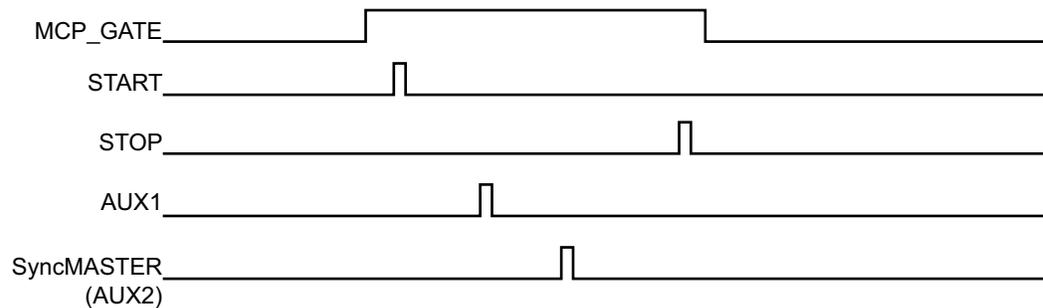
4411-0137_0086

The **EXPOSE** signal remains high for the duration of the pulse set and goes low upon approximately 15 ns after pulse completion.

8.1.1   Supported Timing Generator Trigger Modes

Trigger per Pulse: The pulse set is initiated by its own trigger (either internal or external.) See Figure 8-2.

Figure 8-2:   Timing Diagram: Trigger Per Pulse
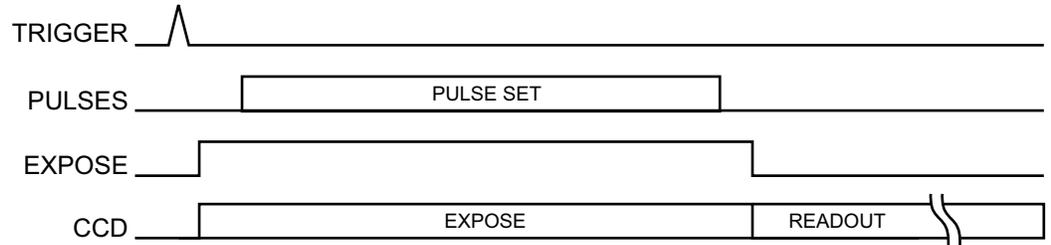
4411-0137_0087

Supported Trigger Sources are:

- **Source 1: Timing Generator internal trigger**
  A pulse set is initiated by the timing generator's internal trigger.
- **Source 2: External Trigger (on TRIGGER IN BNC)**
  A pulse set is initiated by an external trigger.

8.2   Single Sequence

A sequence is the repetition of a single Pulse Set for **X** number of times. Figure 8-3 illustrates a sequence with the pulse set repeated three (3) times.

Figure 8-3:   Timing Diagrams: Three Repetition Sequence
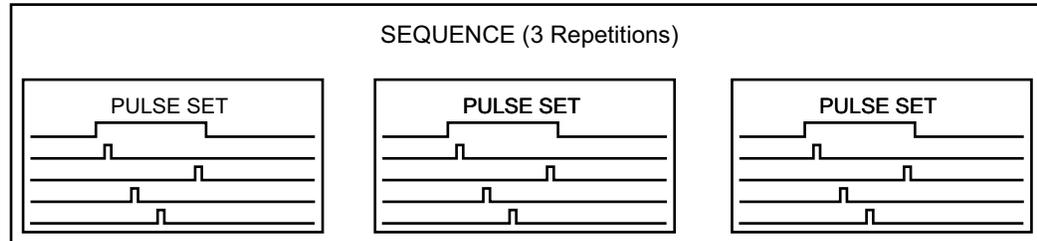
4411-0137_0088

The **EXPOSE** signal remains high for the duration of the sequence and goes low approximately 15 ns after sequence completion.

8.2.1   Supported Timing Generator Trigger Modes

Trigger per Pulse: Each pulse of the single sequence is initiated by its own trigger.

🔍 NOTE: ─────────────────────────

All triggers must be:

- • Generated from the same source, and
- • Must all be either an internal or an external trigger. The use of a combination of internal and external triggers is not supported.

See Figure 8-4.

Figure 8-4:   Timing Diagram: 3 Repetition Sequence, Trigger per Pulse
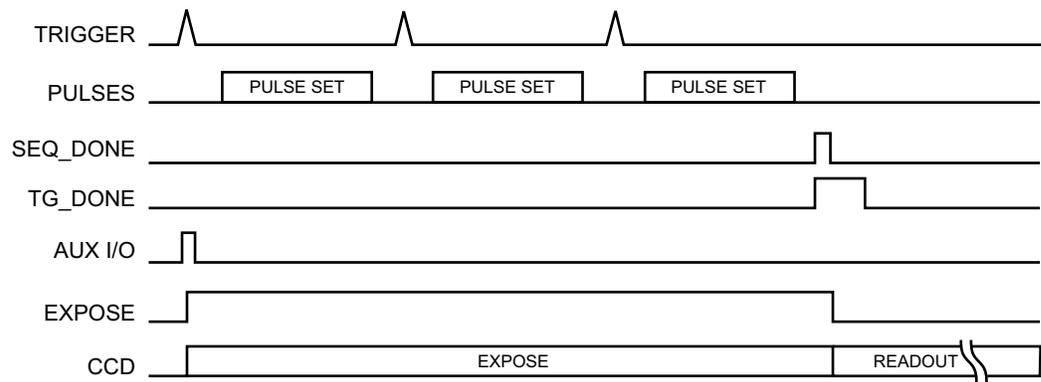
4411-0137_0089

Supported Trigger Sources are:

- • **Source 1: Timing Generator internal trigger**
  Each pulse set of the sequence is initiated by the timing generator's internal trigger.
- • **Source 2: External Trigger (on TRIGGER IN BNC)**
  Each pulse set is initiated by an external trigger.

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Chapter 9:   LightField and Dual Image Feature

The purpose of the PI-MAX4 Dual Image Feature (DIF) is to acquire a pair of gated images in rapid succession. The time between frames can be as short as 450 ns: the second image will have some remnants from the first image due to the longer persistence of the P46 phosphor. Exposure times can be as short as 2.5 ns. The DIF capability is ideally suited to capturing rapidly evolving events. These experiments will fall into one of two broadly applicable categories:

- Readout Per Trigger (i.e., single trigger,) experiments;
  Single trigger experiments involve a single impulse event that evolves over time, such as a laser-induced plasma or luminescence decay.

- Shift Per Trigger (i.e., dual trigger,) experiments.
  Dual trigger experiments involve two impulses separated in time, such as double laser pulse velocimetry measurements.

> **NOTE:**
>
> The PI-MAX4:1024i is currently the only PI-MAX4 camera on which DIF is supported.

9.1   Requirements

For DIF operation, the PI-MAX4 must use an **interline** CCD and DIF must be the selected Readout Mode on the Readout expander,. See Figure 9-1.

Figure 9-1:   Readout Expander
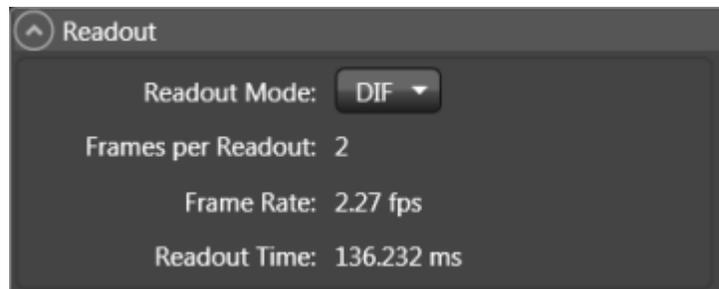
4411-0137_0100

The number of frames must be a multiple of two (2) and is set via the **Common Acquisitions Settings** expander. See Figure 9-2.

Figure 9-2:   Common Acquisition Settings Expander
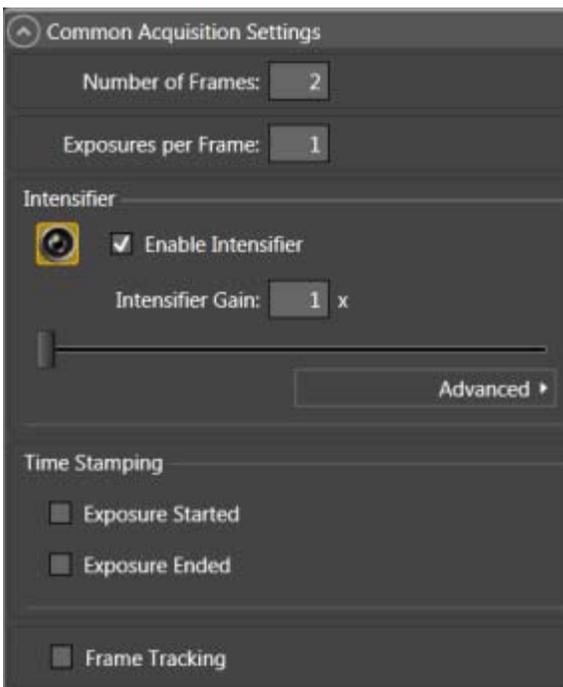
4411-0137_0101

In addition, it is recommended that the intensifier have a fast decay phosphor (P46.) Since DIF operation involves acquiring images in rapid succession, phosphor persistence can become the limiting factor in the rate of image acquisition.

9.2   Interline CCD Operation

An interline CCD is composed of an array of hybrid pixels that incorporate a light-sensitive area and a masked area into each pixel element. Image data is collected in the light-sensitive area of a pixel and is then shifted into the masked area for readout. With this architecture, the CCD can acquire a second image while the first image is being read out, unlike a standard CCD, which must read out the first image before the second acquisition can begin. The ability of the interline CCD to quickly transfer an image into the masked areas and hold it there makes DIF possible. As soon as the first image is acquired, it is shifted into the masked area and held. The second exposure begins and is held in the light-sensitive area until the first image is read out.

9.3   Trigger Setup

Triggering for DIF operation is set up on the Trigger and the SuperSYNCHRO expanders. Trigger setup consists of selecting the trigger response and the trigger source.

9.3.1   Trigger Response

The configured **Trigger Response** determines whether one or two triggers are required for the acquisition. The trigger(s) can either be internally generated by the PI-MAX4 or can be generated by an external source that is connected to the TRIGGER IN connector on the rear of the camera.

The two Trigger Responses are:

- **Readout Per Trigger**
  Two shot, one trigger for both shots.
- **Shift Per Trigger**
  Two shot, each shot requires a trigger.

Trigger Response is configured on the **Trigger** expander. See Figure 9-3.

Figure 9-3:   Trigger Expander

4411-0137_0102
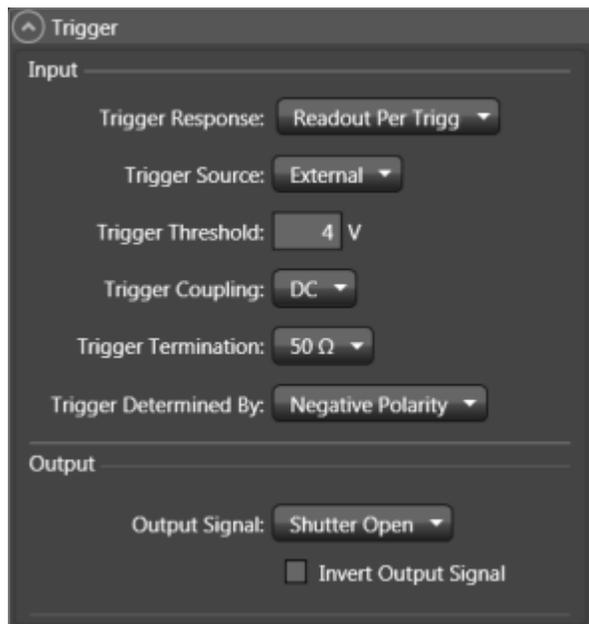
9.3.2   Trigger Source

The trigger source is selectable via the **Trigger Source** drop-down list. The trigger source can either be internal or external and is configured on the **Trigger** expander. See Figure 9-3.

In addition, when using an internal trigger, the frequency is configured via the SuperSYNCHRO expander. See Figure 9-4.

Figure 9-4:   SuperSYNCHRO Timing Expander: DIF Operation
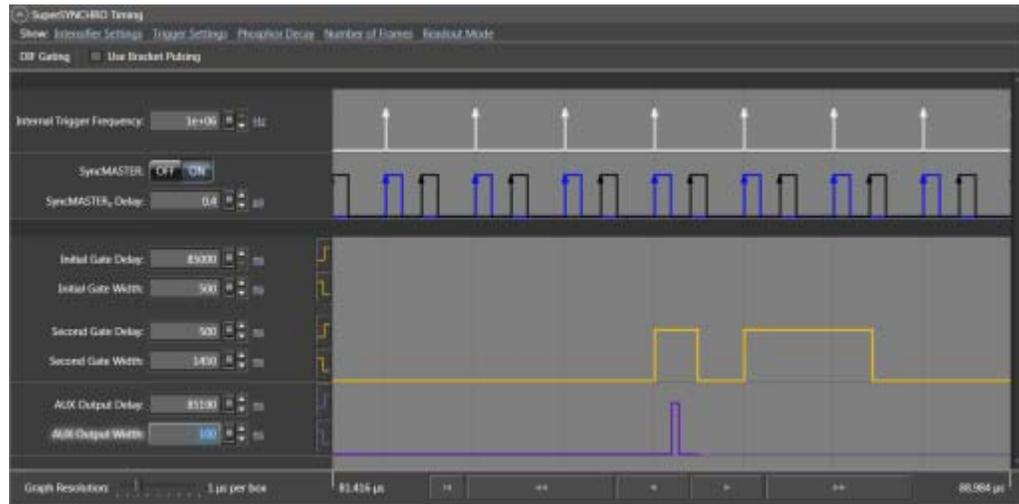
4411-0137_0103

9.3.2.1   Internal Trigger Source

Trigger pulses are generated by the PI-MAX4 based on the Internal Trigger Frequency setting as configured on the **SuperSYNCHRO Timing** expander. The range of settings is 2 Hz to 1 MHz, in 1 Hz increments. Note that the Internal Trigger Frequency setting also determines the frequency of SynchMASTER1 and SyncMASTER2 outputs.

9.3.2.2   External Trigger Source

In order for the PI-MAX4 to recognize triggers from an external source, the characteristics of the triggers to be used in triggering DIF acquisition must be configured. These characteristics include:

- Trigger Threshold;
- Coupling;
- Termination;
- Polarity.

These parameters are configured on the **Trigger** expander.

9.4   Configure a Single Trigger DIF Experiment

This section describes the configuration of a single trigger DIF experiment.

9.4.1   Hardware

Figure 9-5 illustrates a block diagram of the equipment setup.

Figure 9-5:   Block Diagram: DIF Experiment
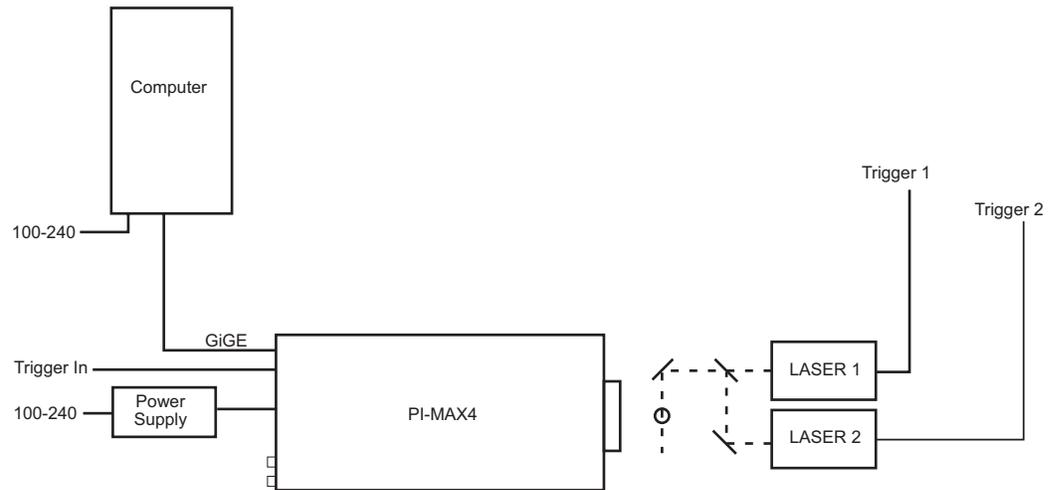
*** SPECTROGRAPH, COOLANT CIRCULATOR, AND DRY
NITROGEN TANK CONNECTIONS ARE OPTIONAL**

4411-0137_0090

9.4.2   Software Configuration and Operation

The operation of the PI-MAX4 in DIF mode is similar to standard operation of a PI-MAX4 with SuperSYNCHRO. This section describes the minor operational differences that are due to the special timing modes required for DIF.

Figure 9-6 illustrates the timing diagram for a single trigger DIF experiment.

Figure 9-6:   Timing Diagram: DIF Operation, Single Trigger

D1 = Initial Gate Delay (≥ 85 us)   D2 = Inter-Pulse Gate Delay
PD = Phosphor Decay Time
W1 = Pulse 1 Gate Width   W2 = Pulse 2 Gate Width

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Perform the following procedure to configure a single trigger DIF experiment:

1. The PI-MAX4 camera must be aligned and focused on the area of interest for this experiment. This is best accomplished while the PI-MAX4 is operating in Full Frame readout mode (i.e., before switching to DIF mode on the **Readout** expander.)

    Verify that the **Phosphor Decay Delay** is appropriate to the phosphor used by the camera. The **Phosphor Decay Delay** time entered in LightField can be viewed or changed by clicking on the **Advanced** button on the **Common Acquisition Settings** expander.

    > **NOTE:**
    >
    > The Phosphor Decay Delay setting is used to tell LightField how long to wait after the gate pulse to shift the image. If there is some residual image from the first frame in the second frame, simply increase the Phosphor Decay Delay setting to allow more time for the phosphor emission to decay before shifting the image. If residual image is not an issue, then the Phosphor Decay Delay setting can be decreased to reduce the time between the two DIF images.

2. After the alignment and focus, the PI-MAX4 system needs to be put into DIF mode.
    *   On the **Readout** expander, select **DIF** as the **Readout Mode**.
    *   On the **Common Acquisitions Settings** expander, configure the **Number of Frames** to a multiple of 2 (i.e., 2, 4, 6, etc.)

3. On the **Trigger** expander, verify that **Trigger Response** is set to **Readout Per Trigger**.

4. On the **Trigger** expander, select **Internal** or **External** triggering.

   When using External triggering, verify the trigger characteristics on the **Trigger** expander match the active trigger edge, etc., for the trigger pulse being used.

   When using Internal triggering, perform the following procedure to configure the **Internal Trigger** parameters on the **SuperSYNCHRO** expander:

   a. Open the **SuperSYNCHRO Timing** expander at the bottom of the window.

   b. Use the hyperlinks at the top of the expanded panel to make any changes to:
      - Intensifier Settings;
      - Trigger Settings;
      - Phosphor Decay Delay Time;
      - Number of Frames (i.e., must be a multiple of 2);
      - Readout Mode (i.e., DIF or Full Frame.)

   c. When using PI-MAX4-generated internal triggers for DIF acquisition, configure the **Internal Trigger Frequency**.

   d. Enter the **Gate Width** and **Gate Delay** times for the first and second images.
      - The **Initial Gate Delay** time will be ≥ 85 µs.
      - The **Second Gate Delay** time will be ≥ 441 µs.

   e. If required, set up **AUX Output Trigger**.

   f. To have trigger output from the SyncMASTER1 and SyncMASTER2 connectors on the AUX I/O cable, click on the **SyncMASTER ON** button. When SyncMASTER is enabled, the output of the SyncMASTER1 connector will be at the Internal Trigger Frequency. The SyncMASTER2 output will be at the same frequency but can be delayed from 0 to 999,700 ns, in 100 ns increments.

5. Verify that the I.I.T. power switch on the rear of the PI-MAX4 is turned ON, and that **Enable Intensifier** has been checked on the **Common Acquisition Settings** expander.

6. When the experiment is ready, click on the **ACQ** button, or select **Acquire** on the **Acquisition** menu, to start image acquisition.

9.5 Configure a Dual Trigger DIF Experiment

This section describes the configuration of a dual trigger DIF experiment.

9.5.1 Hardware

Figure 9-7 illustrates a block diagram of the equipment setup.

Figure 9-7: Block Diagram: DIF Experiment
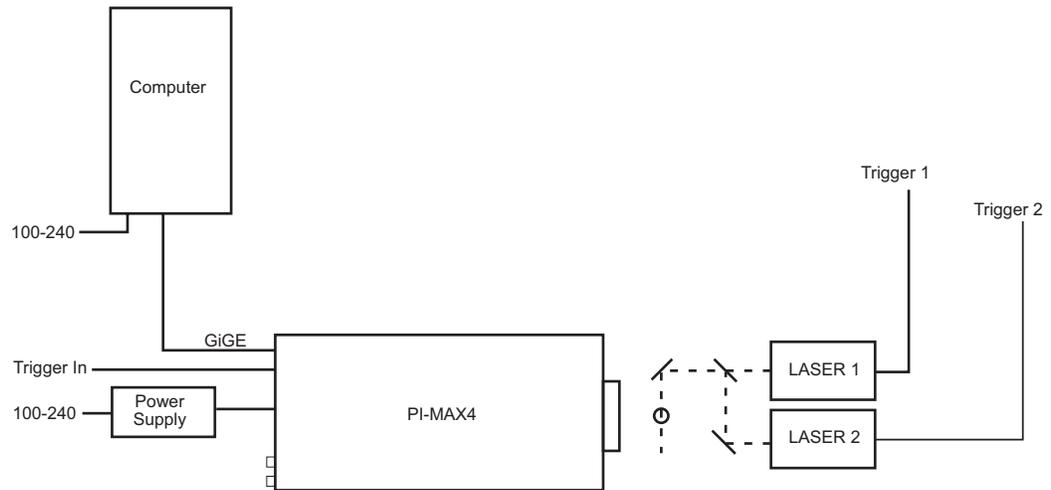
* SPECTROGRAPH, COOLANT CIRCULATOR, AND DRY NITROGEN TANK CONNECTIONS ARE OPTIONAL

4411-0137_0090

9.5.2 Software Setup and Operation

The operation of the PI-MAX4 in DIF mode is similar to the standard operation of a PI-MAX4 with SuperSYNCHRO. There are only a few differences due to the special timing modes of DIF, and they will be outlined here.

Figure 9-8 illustrates the timing diagram for a single trigger DIF experiment.

Figure 9-8: Timing Diagram: DIF Operation, Dual Trigger
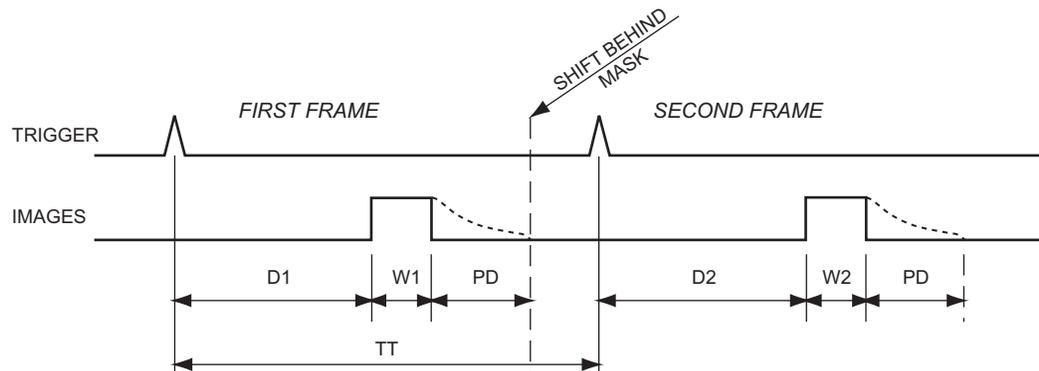
D1 = Initial Gate Delay (≥ 85 us)
PD = Phosphor Decay Time
W1 = Pulse 1 Gate Width
TT = Time between Triggers (≥ D1+w1+PD)

D2 = Pulse 2 Gate Delay (≥ min. delay of camera ~ 25 ns)

W2 = Pulse 2 Gate Width

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Perform the following procedure to configure a dual trigger DIF experiment:

1. The PI-MAX4 camera must be aligned and focused on the area of interest for this experiment. This is best accomplished while the PI-MAX4 is operating in Full Frame readout mode (i.e., before switching to DIF mode on the **Readout** expander.)

Verify that the **Phosphor Decay Delay** is appropriate to the phosphor used by the camera. The **Phosphor Decay Delay** time entered in LightField can be viewed or changed by clicking on the **Advanced** button on the **Common Acquisition Settings** expander.

> **NOTE:**
>
> The Phosphor Decay Delay setting is used to tell LightField how long to wait after the gate pulse to shift the image. If there is some residual image from the first frame in the second frame, simply increase the Phosphor Decay Delay setting to allow more time for the phosphor emission to decay before shifting the image. If residual image is not an issue, then the Phosphor Decay Delay setting can be decreased to reduce the time between the two DIF images.

2. After the alignment and focus, the PI-MAX4 system needs to be put into DIF mode.
   - On the **Readout** expander, select **DIF** as the **Readout Mode**.
   - On the **Common Acquisitions Settings** expander, configure the **Number of Frames** to a multiple of 2 (i.e., 2, 4, 6, etc.)

3. On the **Trigger** expander, verify that **Trigger Response** is set to **Shift Per Trigger**.

4. On the **Trigger** expander, select **Internal** or **External** triggering.

When using External triggering, verify the trigger characteristics on the **Trigger** expander match the active trigger edge, etc., for the trigger pulse being used.

When using Internal triggering, perform the following procedure to configure the **Internal Trigger** parameters on the **SuperSYNCHRO** expander:

a. Open the **SuperSYNCHRO Timing** expander at the bottom of the window.

b. Use the hyperlinks at the top of the expanded panel to make any changes to:
   - Intensifier Settings;
   - Trigger Settings;
   - Phosphor Decay Delay Time;
   - Number of Frames (i.e., must be a multiple of 2);
   - Readout Mode (i.e., DIF or Full Frame.)

c. When using PI-MAX4-generated internal triggers for DIF acquisition, configure the **Internal Trigger Frequency**.

d. Enter the **Gate Width** and **Gate Delay** times for the first and second images.
   - The **Initial Gate Delay** time will be ≥ 85 µs.
   - The **Second Gate Delay** time will be ≥ 441 µs.

e. If required, set up **AUX Output Trigger**.

    f. To have trigger output from the SyncMASTER1 and SyncMASTER2 connectors on the AUX I/O cable, click on the **SyncMASTER ON** button. When SyncMASTER is enabled, the output of the SyncMASTER1 connector will be at the Internal Trigger Frequency. The SyncMASTER2 output will be at the same frequency but can be delayed from 0 to 999,700 ns, in 100 ns increments.

5. Verify that the I.I.T. power switch on the rear of the PI-MAX4 is turned ON, and that **Enable Intensifier** has been checked on the **Common Acquisition Settings** expander.

6. When the experiment is ready, click on the **ACQ** button, or select **Acquire** on the **Acquisition** menu, to start image acquisition.

9.6   Tips and Tricks

Experiments using the DIF feature of the PI-MAX4 can be complex, and timing of the events is usually rather exacting. Here are several points to consider that may make the experiment setup or troubleshooting much smoother and easier.

- The most important piece of equipment in a DIF experiment is an oscilloscope. The PI-MAX4 has a **MONITOR** BNC on the back of the camera which is very useful for seeing when the two image exposures occur during the course of the experiment. The use of the **MONITOR** BNC and an oscilloscope is discussed in greater detail in Chapter 15, Tips and Tricks.

- The short time between the two images in DIF requires an intensifier with a fast phosphor. P46 phosphor has a decay time of ~ 2 µs which means it takes 2 µs for the phosphor emission to drop to 10% of its peak value. The decay is not a simple single exponential; even after 100 µs there may be 1% or more of the first image on the phosphor screen. It is usually possible to subtract a percentage of the first image from the second image to remove the residual image. If this is not possible, there are intensifiers with P47 phosphor, which is an order of magnitude faster than P46.

- The software uses the **Phosphor Decay Delay** to determine how long to wait after the gate to shift the image. This value can be adjusted in the **Advanced** fly-out pane on the **Common Acquisition Settings** expander. If there is some residual image from the first frame in the second frame, simply increase the Phosphor Decay Delay to allow the phosphor more time to decay before shifting the image. If residual image is not an issue, then Phosphor Decay Delay can be shortened to decrease the time between the two DIF images. This setting has no effect on the actual phosphor decay time. It is only used to adjust timing.

Chapter 10: WinX and Dual Image Feature

The purpose of PI-MAX4 Dual Image Feature (DIF) is to acquire a pair of gated images in rapid succession with delay time between two images as short as 450 ns. The second image will have some remnants from the first image due to the longer persistence of the P46 phosphor. Exposure times can be as short as 2.5 ns. The DIF capability is ideally suited to capturing rapidly evolving events. These experiments will fall into one of two broadly applicable categories:

- Single Trigger experiments;
  Single trigger experiments involve a single impulse event that evolves over time, such as a laser-induced plasma or luminescence decay.

- Dual Trigger experiments.
  Dual trigger experiments involve two impulses separated in time, such as double laser pulse velocimetry measurements.

> **NOTE:**
>
> The PI-MAX4:1024i is currently the only PI-MAX4 camera on which DIF is supported.

10.1   Requirements

The PI-MAX4 must use an interline CCD. In addition, it is recommended that the intensifier have a fast decay phosphor (P46.) Since DIF operation involves acquiring images in rapid succession, phosphor persistence can become the limiting factor in the rate of image acquisition.

WinView or WinSpec software (version 2.5.26 or higher) can control the DIF functionality of the PI-MAX4 and provide full access to the two DIF timing modes: single trigger and dual trigger.

10.2   Interline CCD Operation

An interline CCD is composed of an array of hybrid pixels that incorporate a light-sensitive area and a masked area into each pixel element. Image data is collected in the light-sensitive area of a pixel and is then shifted into the masked area for readout. With this architecture, the CCD can acquire a second image while the first image is being read out, unlike a standard CCD, which must read out the first image before the second acquisition can begin. The ability of the interline CCD to quickly transfer an image into the masked areas and hold it there makes DIF possible. As soon as the first image is acquired, it is shifted into the masked area and held. The second exposure begins and is held in the light-sensitive area until the first image is read out.

10.3 Timing Modes

The following two DIF timing/readout modes are available in WinX:

- **Single Trig. Mode**
  Two shot, one trigger for both shots.
- **Dual Trig. Mode**
  Two shot, each shot requires a trigger.

The trigger(s) can be generated by an external source connected to the PI-MAX4 or the PI-MAX4 can generate the trigger(s) internally. In WinX, DIF readout is selected on the **Hardware Setup —> Controller/Camera** tab. The timing mode (single or dual trigger) is selected on the **Acquisition —> Experiment Setup… —> Timing** tab.

10.4 Configure a Single Trigger DIF Experiment

This section describes the configuration of a single trigger DIF experiment.

10.4.1 Hardware

Figure 10-1 illustrates a block diagram of the equipment setup.

Figure 10-1: Block Diagram: DIF Experiment
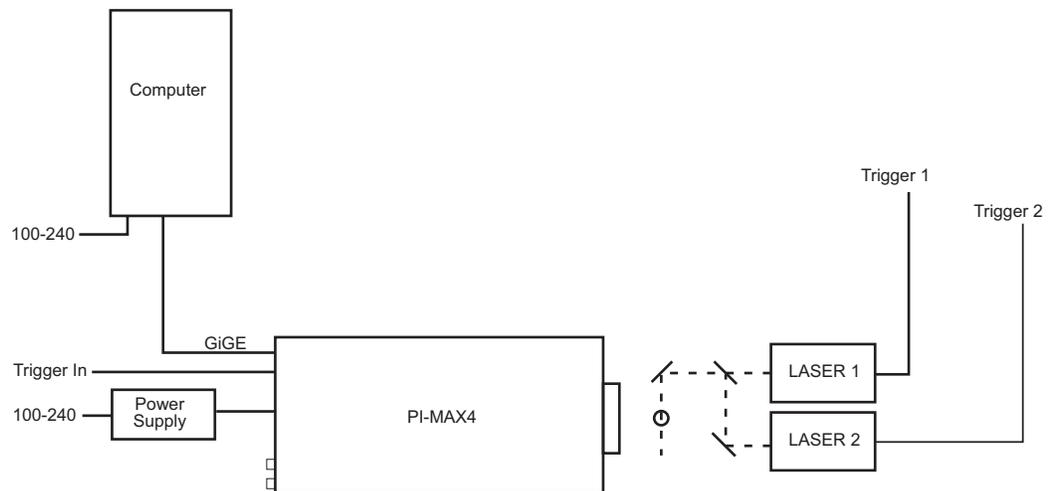
* SPECTROGRAPH, COOLANT CIRCULATOR, AND DRY
NITROGEN TANK CONNECTIONS ARE OPTIONAL

4411-0137_0090

10.4.2 Software

For the purposes of this experiment, it is assumed that either WinView or WinSpec is being used to control the system.

10.4.3 Operation

The operation of the PI-MAX4 in DIF mode is similar to standard operation of a PI-MAX4 with SuperSYNCHRO. This section describes the minor operational differences that are due to the special timing modes required for DIF.

Figure 10-2 illustrates the timing diagram for a single trigger DIF experiment.

Figure 10-2: Timing Diagram: DIF Operation, Single Trigger
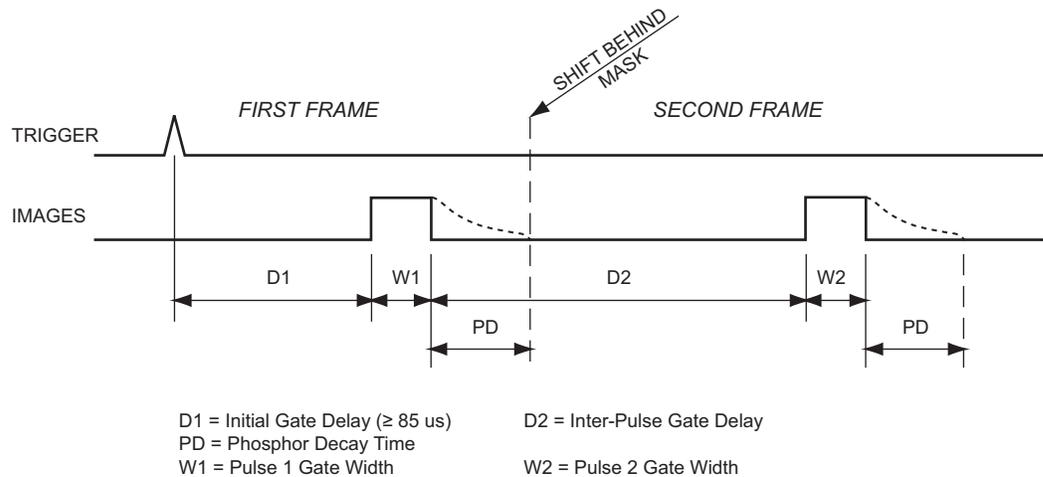
D1 = Initial Gate Delay (≥ 85 us)   D2 = Inter-Pulse Gate Delay
PD = Phosphor Decay Time
W1 = Pulse 1 Gate Width   W2 = Pulse 2 Gate Width

4411-0137_0091

Perform the following procedure to configure a single trigger DIF experiment:

1. The PI-MAX4 camera must be aligned and focused on the area of interest for this experiment. This is best accomplished while the PI-MAX4 is operating in Interline mode (i.e., before switching to DIF mode.)

> **REFERENCES:** ──────────────
>
> Refer to Chapter 4, First Light, for information about the initial focusing of the camera.

Verify that the **Phosphor Decay Time** is appropriate to the phosphor used by the camera. This field is located on the **Setup —> Hardware Setup —> Controller/Camera** tab. See Figure 10-3.

Figure 10-3: WinX Hardware Setup Dialog: Controller/Camera Tab
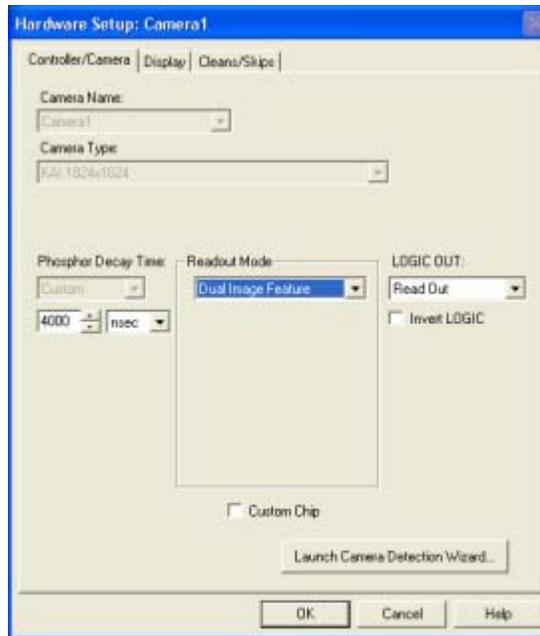
4411-0137_0092

2. After the alignment and focus, the PI-MAX4 system needs to be put into DIF mode. On the **Setup —> Hardware Setup —> Controller/Camera** tab, select **Dual Image Feature** as the **Readout Mode**, and then click **OK**.

3. The PI-MAX4 must be configured for **Gate Mode** in order for the intensifier to operate properly. Either click on the **Gate** mode button on the Custom Toolbar, or select **Gate Mode** on the **Acquisition —> Experiment Setup… —> Main** tab. See Figure 10-4.

Figure 10-4: WinX Experiment Setup Dialog: Main Tab
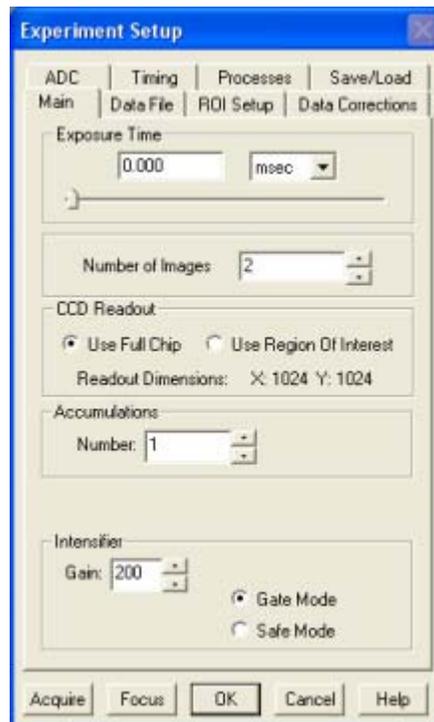
4411-0137_0093

4. On the **Acquisition —> Experiment Setup… —> Timing** tab, verify that **Single Trig. Mode** is the selected timing mode. Additionally, **Continuous Cleans** is recommended for DIF. See Figure 10-5.

Figure 10-5: WinX Experiment Setup Dialog: Timing Tab

4411-0137_0094

5. From the **Setup** menu, select **Pulsers**. See Figure 10-6.

Figure 10-6: WinX Pulsers Dialog
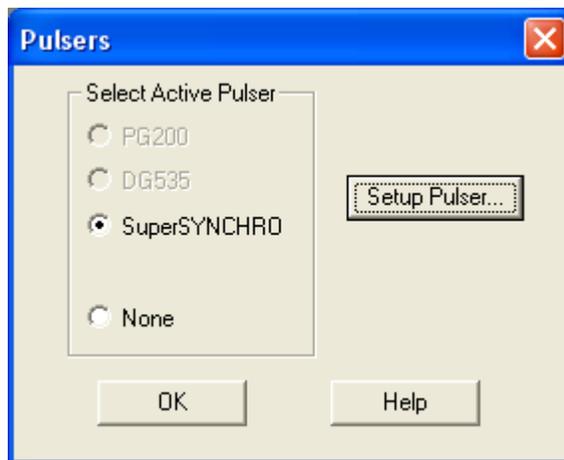
4411-0137_0009

6. Select **SuperSYNCHRO**, and click the **Setup Pulser** button to display the **SuperSYNCHRO** dialog.

7. Click on the **Gating** tab, select **DIF Gating,** and click on the **Setup** button. See Figure 10-7.

Figure 10-7: WinX SuperSYNCHRO Dialog: Gating Tab

4411-0137_0095

8. On the **DIF Gating Setup** dialog, enter the desired **Gate Width** and **Gate Delay** times.

    • When entering the **Initial Gate Delay** time, verify that it is ≥ 85 µs.

    • When entering the **Inter-Pulse Gate Delay** time, verify that the delay is greater than or equal to the Phosphor Decay Time as configured on the **Setup —> Hardware Setup —> Controller/ Camera** tab.

    See Figure 10-8.

Figure 10-8: WinX DIF Gating Setup Dialog
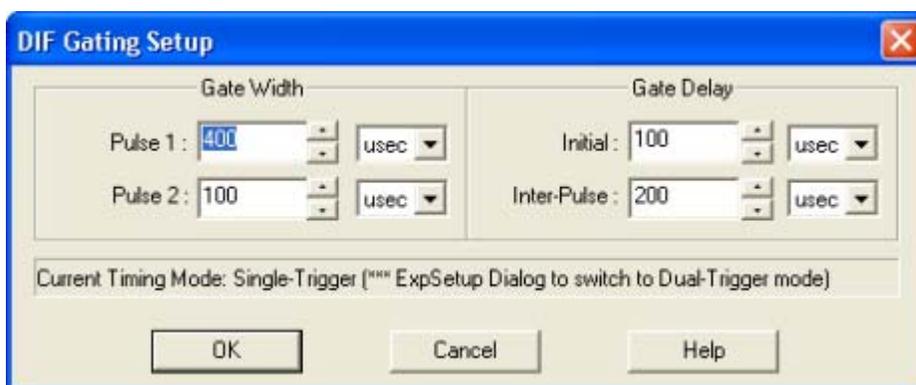
4411-0137_0096

9. Click on the **Trigger In** tab, and select **Internal** or **External** triggering.

When using External triggering, verify the trigger characteristics match the active trigger edge, etc., for the trigger pulse being used.

See Figure 10-9.

Figure 10-9: WinX SuperSYNCHRO Dialog: Trigger In Tab
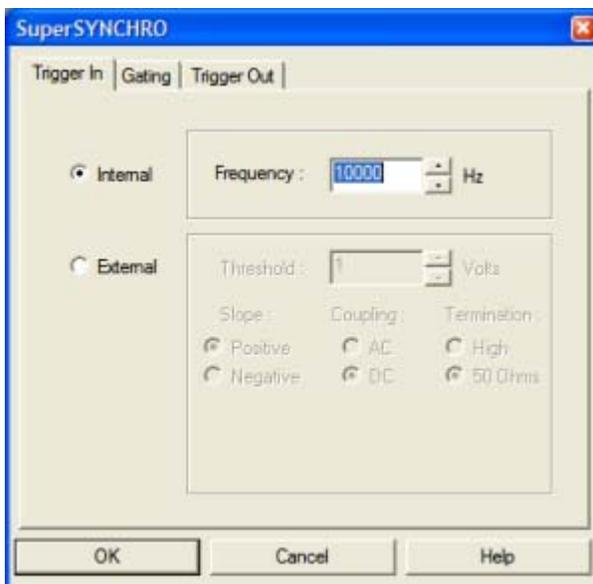
4411-0137_0010

10. If required, click on the **Trigger Out** tab to configure output triggers. See Figure 10-10.

Figure 10-10: WinX SuperSYNCHRO Dialog: Trigger Out Tab

4411-0137_0059

11. Click **OK** to dismiss the **SuperSYNCHRO** dialog and download the gating sequence to the SuperSYNCHRO.

12. When the experiment is ready, click on the **ACQ** button, or select **Acquire** on the **Acquisition** menu, to start image acquisition.

10.5   Configure a Dual Trigger DIF Experiment

This section describes the configuration of a dual trigger DIF experiment.

10.5.1   Hardware

Figure 10-11 illustrates a block diagram of the equipment setup.

Figure 10-11:Block Diagram: DIF Experiment

* SPECTROGRAPH, COOLANT CIRCULATOR, AND DRY
  NITROGEN TANK CONNECTIONS ARE OPTIONAL
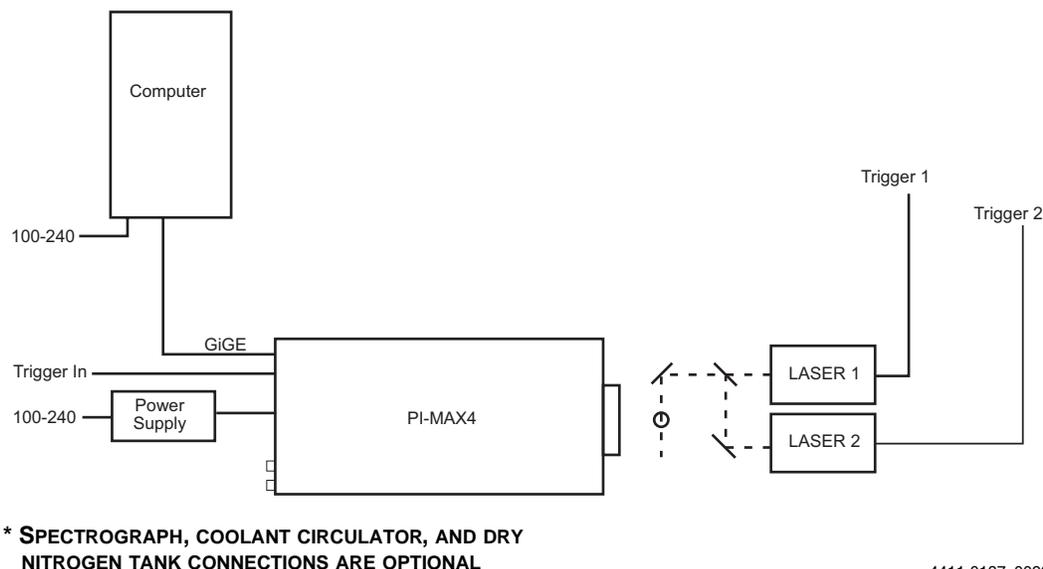
4411-0137_0090

10.5.2   Software

For the purposes of this experiment, it is assumed that either WinView or WinSpec is being used to control the system.

10.5.3   Operation

The operation of the PI-MAX4 in DIF mode is similar to the standard operation of a PI-MAX4 with SuperSYNCHRO. There are only a few differences due to the special timing modes of DIF, and they will be outlined here.

Figure 10-12 illustrates the timing diagram for a single trigger DIF experiment.

Figure 10-12:Timing Diagram: DIF Operation, Dual Trigger
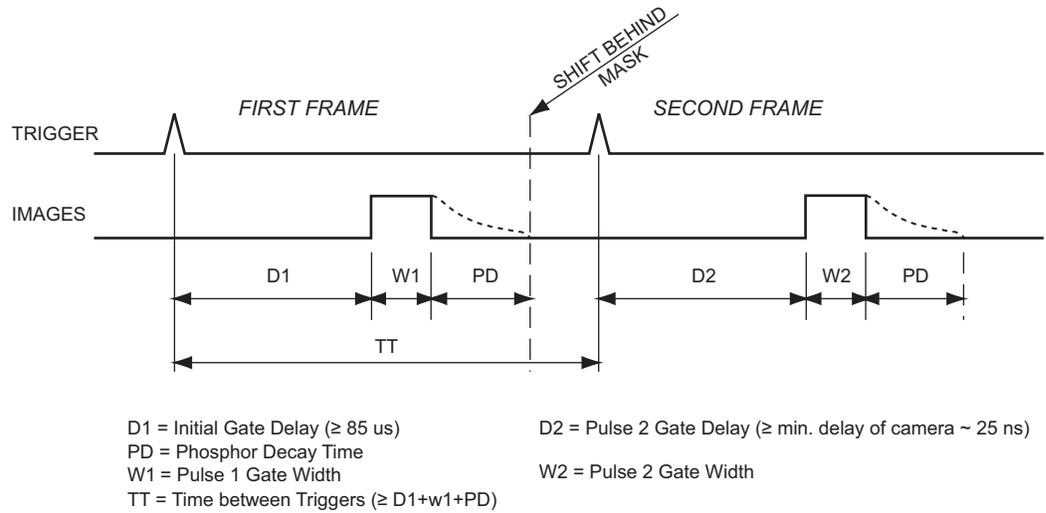
D1 = Initial Gate Delay (≥ 85 us)   D2 = Pulse 2 Gate Delay (≥ min. delay of camera ~ 25 ns)
PD = Phosphor Decay Time
W1 = Pulse 1 Gate Width   W2 = Pulse 2 Gate Width
TT = Time between Triggers (≥ D1+w1+PD)

4411-0137_0097

Perform the following procedure to configure a dual trigger DIF experiment:

1. The PI-MAX4 camera must be aligned and focused on the area of interest for this experiment. This is best accomplished while the PI-MAX4 is operating in Interline mode (i.e., before switching to DIF mode.)

> 📖 **REFERENCES:** ────────────────
>
> Refer to Chapter 4, First Light, for information about the initial focusing of the camera.

Verify that the **Phosphor Decay Time** is appropriate to the phosphor used by the camera. his field is located on the **Setup —> Hardware Setup —> Controller/Camera** tab. See Figure 10-13.

Figure 10-13:WinX Hardware Setup Dialog: Controller/Camera Tab
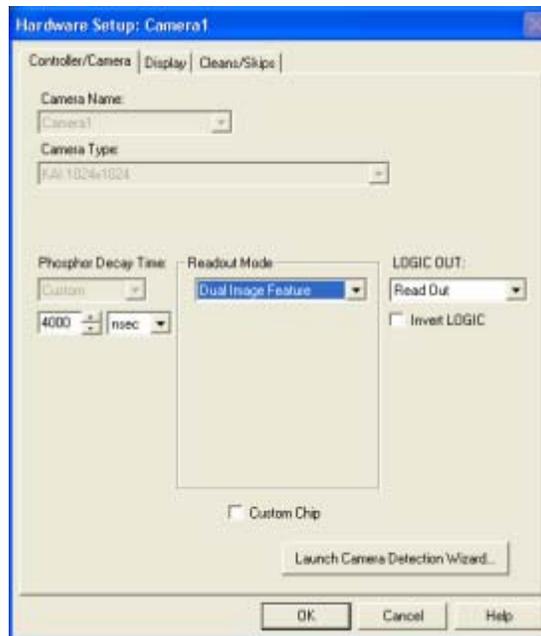
4411-0137_0092

2. After the alignment and focus, the PI-MAX4 system needs to be put into DIF mode. On the **Setup —> Hardware Setup —> Controller/Camera** tab, select **Dual Image Feature** as the **Readout Mode**, and then click **OK**.

3. The PI-MAX4 must be configured for **Gate Mode** in order for the intensifier to operate properly. Either click on the **Gate** mode button on the Custom Toolbar, or select **Gate Mode** on the **Acquisition —> Experiment Setup… —> Main** tab. See Figure 10-14.

Figure 10-14: WinX Experiment Setup Dialog: Main Tab
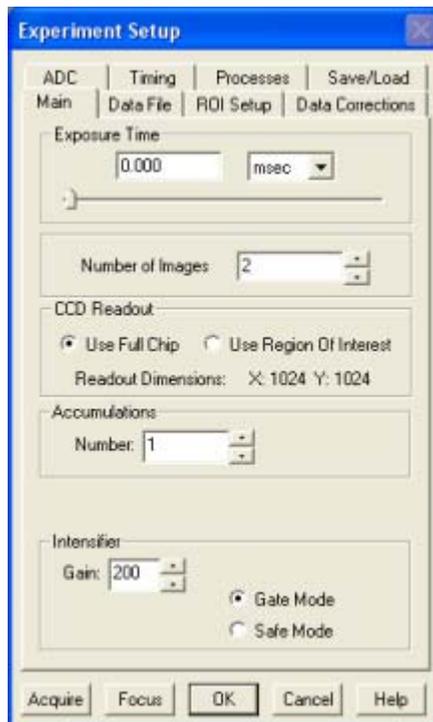
4411-0137_0093

4. On the **Acquisition —> Experiment Setup… —> Timing** tab, verify that **Dual Trig. Mode** is the selected timing mode. Additionally, **Continuous Cleans** is recommended for DIF. See Figure 10-15.

Figure 10-15:WinX Experiment Setup Dialog: Timing Tab
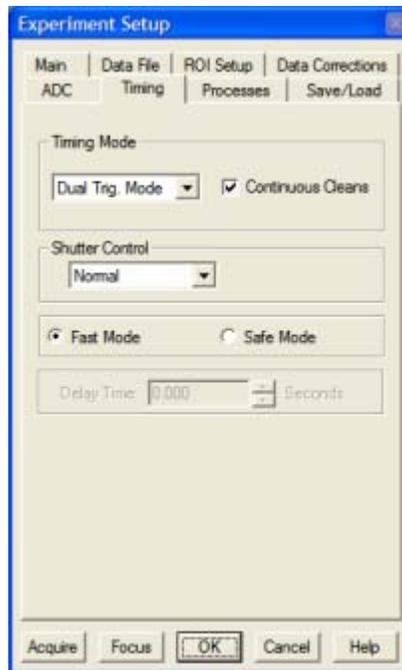
4411-0137_0098

5.   From the **Setup** menu, select **Pulsers**. See Figure 10-16.

Figure 10-16:WinX Pulsers Dialog

4411-0137_0009

6.   Select **SuperSYNCHRO**, and click the **Setup Pulser** button to display the
      SuperSYNCHRO dialog.

7. Click on the **Gating** tab, select **DIF Gating**, and click on the **Setup** button. See Figure 10-17.

Figure 10-17: WinX SuperSYNCHRO Dialog: Gating Tab
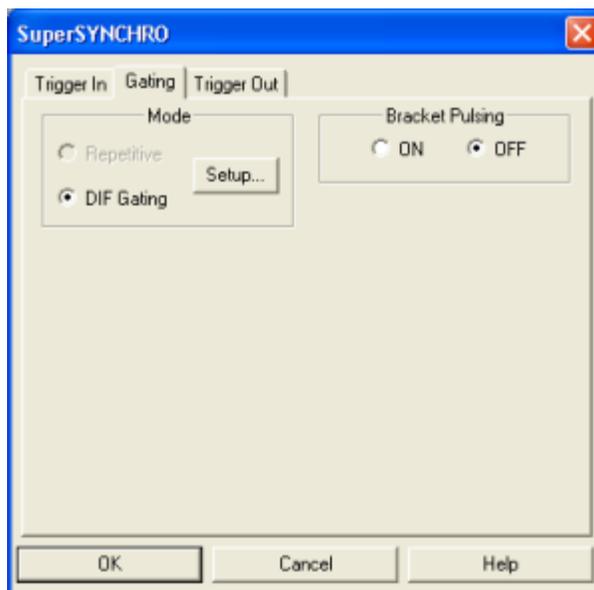
4411-0137_0095

8. On the **DIF Gating Setup** dialog, enter the desired **Gate Width** and **Gate Delay** times. When entering the **Pulse 1 Gate Delay** time, verify that it is ≥ 85 µs.

See Figure 10-18.

Figure 10-18: WinX DIF Gating Setup Dialog: Dual Trigger
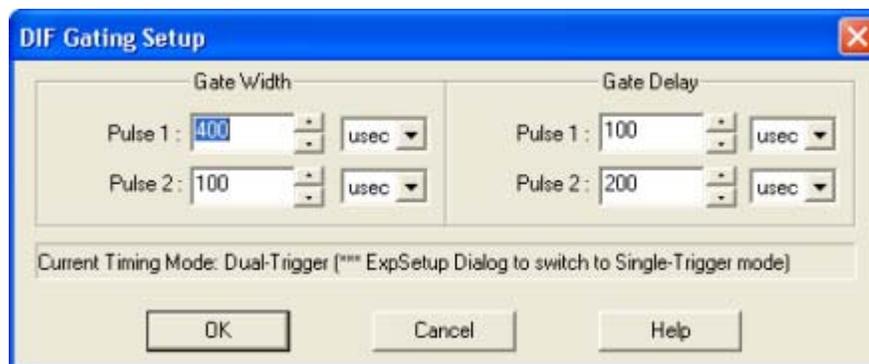
4411-0137_0099

9. Click on the **Trigger In** tab, and select **Internal** or **External** triggering.

When using External triggering, verify the trigger characteristics match the active trigger edge, etc., for the trigger pulse being used.

See Figure 10-19.

Figure 10-19:WinX SuperSYNCHRO Dialog: Trigger In Tab
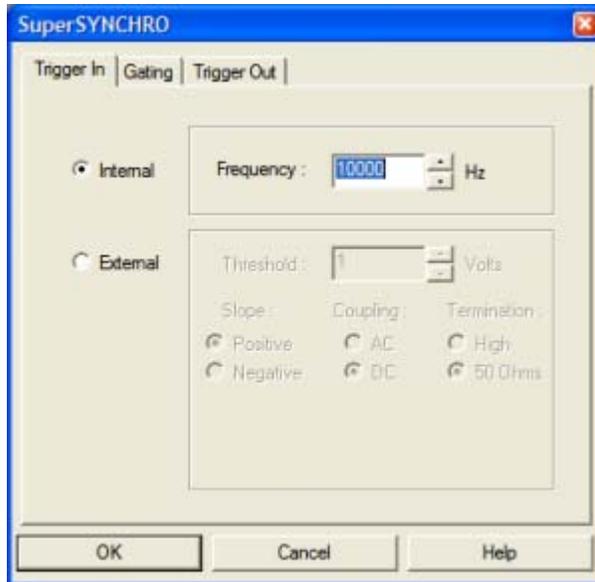
4411-0137_0010

10. If required, click on the **Trigger Out** tab to configure output triggers. See Figure 10-20.

Figure 10-20:WinX SuperSYNCHRO Dialog: Trigger Out Tab

4411-0137_0059

11. Click **OK** to dismiss the **SuperSYNCHRO** dialog and download the gating sequence to the SuperSYNCHRO.

12. When the experiment is ready, click on the **ACQ** button, or select **Acquire** on the **Acquisition** menu, to start image acquisition.

10.6   Tips and Tricks

Experiments using the DIF feature of the PI-MAX4 can be complex, and timing of the events is usually rather exacting. Here are several points to consider that may make the experiment setup or troubleshooting much smoother and easier.

- The most important piece of equipment in a DIF experiment is an oscilloscope. The PI-MAX4 has a **MONITOR** BNC on the back of the camera which is very useful for seeing when the two image exposures occur during the course of the experiment. The use of the **MONITOR** BNC and an oscilloscope is discussed in greater detail in Chapter 15, Tips and Tricks.

- The short time between the two images in DIF requires an intensifier with a fast phosphor. P46 phosphor has a decay time of ~ 2 μs which means it takes 2 μs for the phosphor emission to drop to 10% of its peak value. The decay is not a simple single exponential; even after 100 μs there may be 1% or more of the first image on the phosphor screen. It is usually possible to subtract a percentage of the first image from the second image to remove the residual image. If this is not possible, there are intensifiers with P47 phosphor, which is an order of magnitude faster than P46.

- The software uses the Phosphor Decay Time to determine how long to wait after the gate to shift the image. This value can be adjusted in the Hardware Setup dialog. If there is some residual image from the first frame in the second frame, simply increase the Phosphor Decay Time to allow the phosphor more time to decay before shifting the image. If residual image is not an issue, then Phosphor Decay Time can be shortened to decrease the time between the two DIF images.

Chapter 11: MCP Gating Option

In MCP Gating (not to be confused with MCP bracket pulsing,) the micro-channel plate (MCP) is gated, and the photocathode gating brackets the high speed, 800 V, MCP gating pulse. This technology allows fast gating (<10 ns) of the Super Blue (SB,) slow gate intensifiers (typical gating speed ~ 200 ns) without sacrificing high QE.

The main limitations with this option are that there is a somewhat larger propagation delay and larger optical FWHM than for a standard fast gate PI-MAX4. Insertion delay between trigger and T0 is ~18 ns. Insertion delay to the photocathode gate is ≥ 30 ns. Insertion delay to MCP gate is 80-205 ns, depending on the individual intensifier. This delay allows the photocathode to be fully **ON** before the MCP is gated. Pulse repetition rate is limited to 8 kHz.

The PI-MAX4-MG camera uses a different High Voltage (HV)/Gating board than the standard PI-MAX4 camera and is only available with Super Blue, slow gate intensifier tubes.

NOTE: ───────────────────────────────────
The PI-MAX4-RF does not support picosecond gating.

Figure 11-1: Timing Diagram: Normal Gated Operation
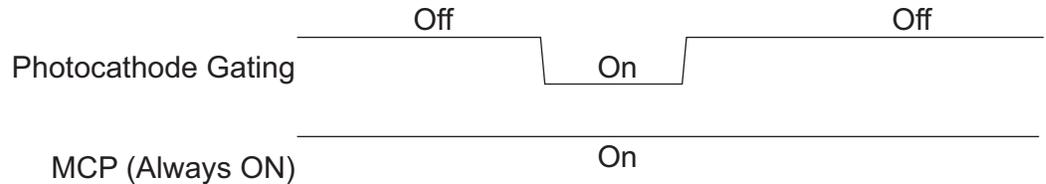
4411-0137_0104

Figure 11-2: Timing Diagram: MCP Bracket Pulsing Operation
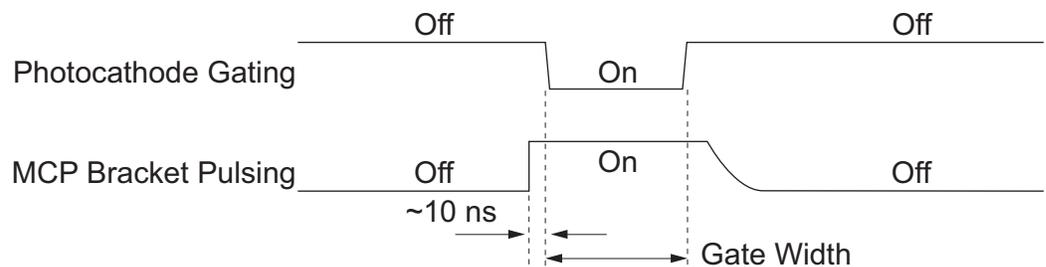
4411-0137_0105

Figure 11-3: Timing Diagram: MCP Gated Operation for Gen II Intensifiers

* **LEAD TIME IS TUBE DEPENDENT AND IS INDIVIDUALLY CALIBRATED AT THE FACTORY.**
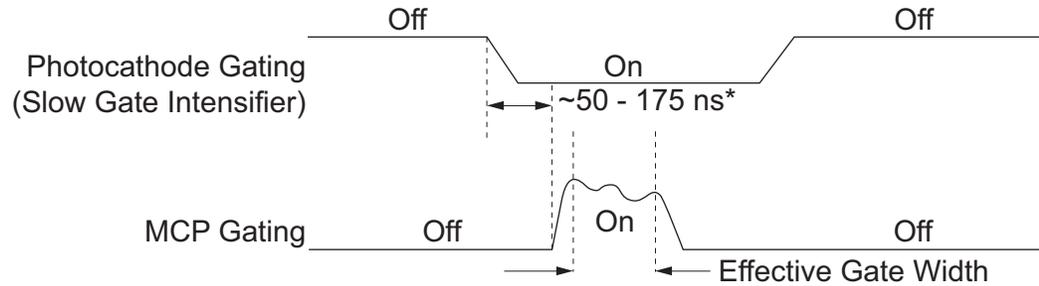
4411-0137_0106

Figure 11-4: QE Curves: Gen II Intensifiers
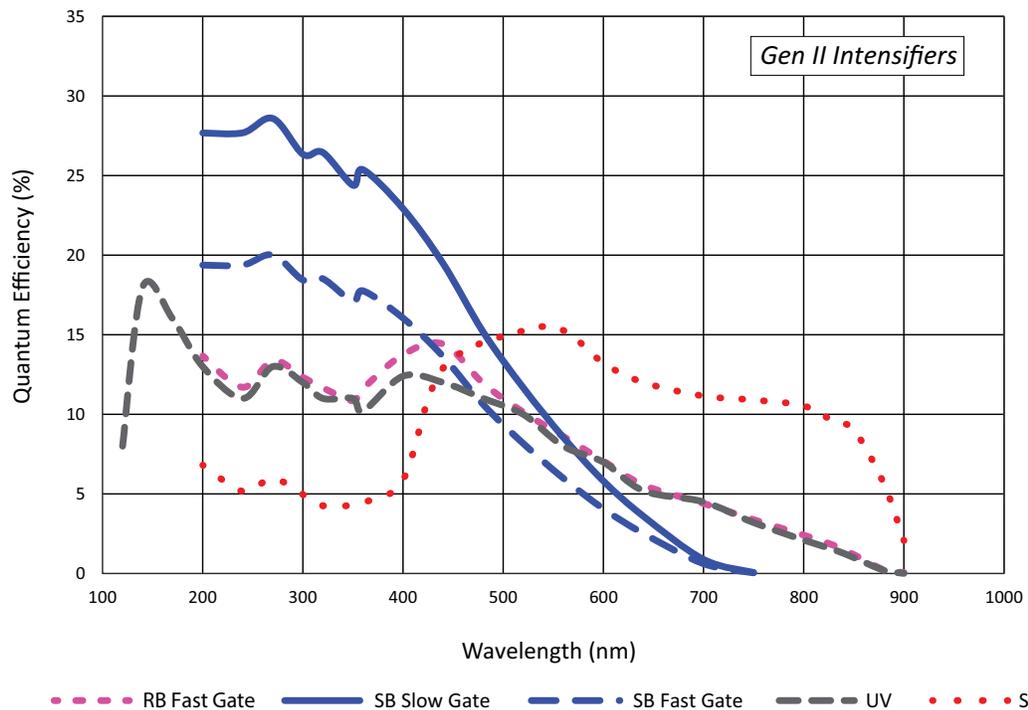
4411-0137_0107

11.1 Setup and Operation

The PI-MAX4 must have an installed MCP Gating board.

- Make all of the required cable connections for the experiment.
- Apply power to the equipment and launch the application software.
- Configure the gating parameters. Start with a relatively long gate to acquire the phenomenon of interest.
- Begin running the experiment.
- Finally, narrow down the gate to the desired operation.

> **NOTE:** ───────────────────────────
>
> Pulse repetition rate is limited to 8 kHz.

11.2   Gain Variation

MCP gain approximately doubles for each 50 V increase in voltage. Therefore, small ripples in the MCP voltage as a result of the gating waveform will cause gain changes that vary with time after the rising edge of the gate pulse. A gain overshoot of 20% to 30% during the first 20 ns of a gate pulse is typical, with smaller variations later in time if a wider gate pulse is used. For a given gain setting and pulse width, these variations are reasonably repeatable, and may be calibrated.

11.3   Fluorescence Experiment

A typical laser-induced fluorescence experiment might incorporate a pulsed laser that excites a sample with the laser beam and that additionally provides a trigger to the PI-MAX4. When the laser pulse hits the sample, some atoms are raised to a higher energy state and then spontaneously relax to the ground state, emitting photons as they do to generate the fluorescence signal. This signal can be applied to a spectrograph that spreads the fluorescence spectrum across the photocathode of the PI-MAX4. The spectrum would then be intensified and applied to the PI-MAX4's CCD array.

11.4   Cabling for MCP Gated Operation

Figure 11-5 illustrates the cabling for an MCP gated experiment using SuperSYNCHRO. The laser trigger output is applied to the PI-MAX4's **Trigger In** connector to initiate the timing sequence. SuperSYNCHRO outputs gate the MCP on and off. To prevent artifacts from the laser from degrading the data, it is essential that SuperSYNCHRO be inhibited during each readout.

Figure 11-5: Block Diagram: MCP Gated Operation Cabling

4411-0137_0108
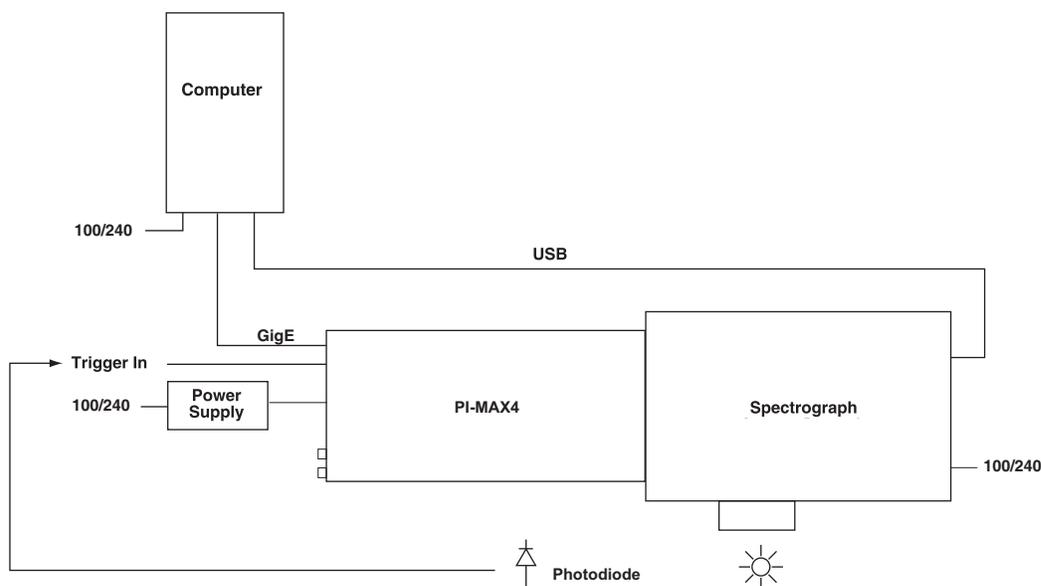
Figure 11-6 is a timing diagram for MCP gating of the photocathode.

Figure 11-6: Timing Diagram: MCP Gated Operation

Trigger In		
~18 ns		
T0		T0
MCP Gating	Off / On / Off	MCP Gating
80 - 205 ns*		
Photocathode Gating	Off / ≥ 30 ns / On / 50 - 175 ns** / Off	Photocathode Gating
T0		T0 remains high for the duration of the pulse ensemble.
Gate Start		Switches MCP ON
Gate Stop		Switches MCP OFF
Bracket		Gates Photocathode ON and OFF
Aux Out		Delay is programmable.
Optical Response		Typical Gain vs. Time Profile (shows some ringing)
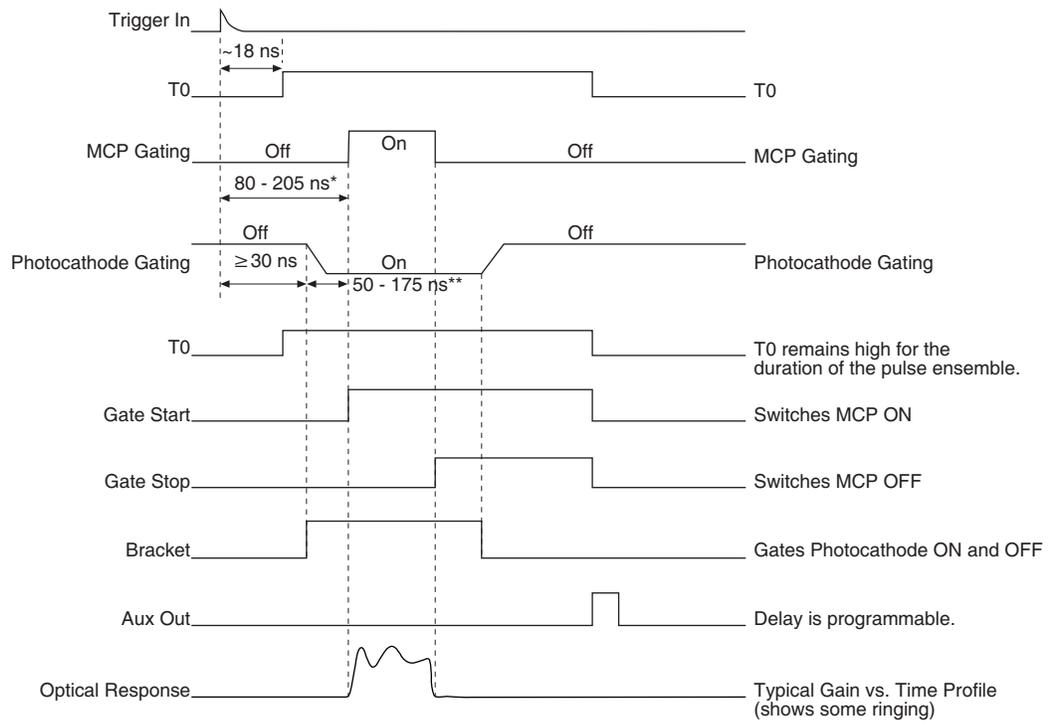
* T_d+T_{pk} typical. Depends on individual image intensifier

** Depends on individual image intensifier

4411-0137_0109

Chapter 12: Picosecond Gating Option

The picosecond gating option for the PI-MAX4 allows optical gates down to less than 500 ps or to the lowest gate width the intensifier will support, whichever is greater. It consists of a picosecond gating board installed in the PI-MAX4 and some other modifications to support the board. The picosecond option can operate up to 100 kHz repetition rate[1] (the main gate generator goes to 1 MHz) and has a few nanoseconds larger insertion delay than the main gate generator. The **MONITOR** BNC output operates differently in picosecond operation.

> **NOTE:**
> The PI-MAX4-RF does not support picosecond gating.

12.1 Activating Picosecond Operation

WinX: Automatically selects the picosecond gating board whenever the gate width is set below 3 ns.

LightField: The **Picosecond Widths** button ⟦Picosecond Widths ▾⟧ is added to the **SuperSYNCHRO Timing** expander when a PI-MAX4 containing the picosecond gating board is detected and loaded as an experiment device.
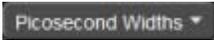
12.2 Gain and Gate Width

The apparent gain of the intensifier falls off as the gate width is reduced. Typically, at the lower limit, the gain is less than 10% of the value observed at 50 ns.

- **WinX**
  The software automatically selects the appropriate gate pulse generator to use when the user selects a gate width: the standard switch-over width is 3 ns.

- **LightField**
  The user selects one of the available gate widths from the **Picosecond Widths** drop down list and that width will be automatically entered in the **Gate Width** field(s.)

> **NOTE:**
> When Sequential Gating is active, the starting and ending gate widths are the same - there are **NO** gate width sequences. However, different starting and ending gate delays (swept delay) can be used with a constant gate width.

---

1. Refer to Section 12.4, Repetition Rate Issues, for additional information about achievable repetition rates.

12.3   MONITOR Operation

The **MONITOR** output at the BNC on the rear panel may be used with an oscilloscope to determine when the intensifier is being gated on. The **MONITOR** output is calibrated to provide a rising edge at the time the optical gate is opening (±500 ps.) The start of the **MONITOR** pulse coincides with the opening of the intensifier, but the width of the **MONITOR** pulse is unrelated to the total intensifier ON time. Refer to Section 5.6.1.1, Exposure Timing, on page 68 for additional information.

Many users do not have oscilloscopes available that can reliably capture picoseconds pulse widths. Therefore, a pulse width of ~6 ns is used independent of the configured gate width. The true optical gate width is shown in the application software and is calibrated at the factory using a fast pulsed laser.

12.4   Repetition Rate Issues

NOTE:

New, sub-nanosecond gate generators are capable of sustaining repetition rates of 100 kHz and therefore the information included in this section is not relevant.

However, when using an older gate generator device, the information included in this section must be considered.

Refer to the manufacturer-supplied technical specifications for the gate generator being used to determine if it is capable of sustaining 100 kHz repetition rates.

The picosecond gate generator operates at high peak power levels and therefore has a lower repetition rate capability than the main gate generator. The normal peak repetition rate for the picosecond gate generator is 100 kHz. However, it will allow 2 gates to be generated at up to 1 MHz to allow for DIF operation. In addition, the 100 kHz repetition rate cannot be sustained continuously. Practically, it must be interrupted periodically to read the CCD so this is not as great a problem as it may seem. The picosecond gate generator includes a digital average duty factor limiting circuit that will lock out gating (and light the red LED on the rear panel) to limit the average heat buildup in the gating circuit. This allows continuous operation at 10 kHz, and varying numbers of gates per frame at higher rates, depending on the read out time. Acquisitions of a few frames can usually be done with more gates per frame without hitting the limit and red light. Some typical numbers for sustained operation with a PI-MAX4:1024i are provided in Table 12-1.

Table 12-1: Typical Picosecond Gating Information: PI-MAX4:1024i

Repetition Rate (kHz)	ADC Rate (MHz)	Binning and ROI	Readout Time (ms)	Gates/Frame
90	16	Full frame	~40	450
75	16	Full frame	~40	461
50	16	Full frame	~40	500
50	16	1Hx100V ROI	~3.4	145
25	16	Full frame	~40	666
10	any	any		No limit

12.5   Timing

When using optical gate widths from a few nanoseconds to a fraction of a nanosecond, timing is obviously critical. The PI-MAX4 is calibrated with respect to the optical input plane (located on the front mounting plane) and the rear panel. All other propagation paths must be accounted for by the user. These are significant, considering a 1 meter coaxial cable represents typically 4.5 ns delay, or 9 times the gate width, assuming the gate width is set to 500 ps. To get the best representation of the **MONITOR** output, the user should use a high bandwidth oscilloscope set at 50 Ω input impedance. The rise time of the **MONITOR** pulse is typically less than 500 ps when terminated in 50 Ω.

12.6   Methods for Finding a Short Optical Pulse

Two methods of identifying a short optical pulse are described in this section.

1. The first method is to calculate all delays in the optical and trigger paths, and configure the PI-MAX4 delay accordingly. If all arithmetic is correct and accurate numbers have been used for all of the delays involved, this method will work. In practice, however, it seldom works because either some of the delays are not accurately known or something gets overlooked. The sum of the optical delays must be greater than the trigger delay (including the PI-MAX4 minimum delay.) Summing after the fact is still a valuable check on the system, even if the timing is achieved by method 2.

2. A more direct and usually more convenient method is to start with a gate pulse much wider than the optical pulse and set the PI-MAX4 so the optical gate is wide enough to be sure it encompasses the optical pulse. This method works well if the pulse is conveniently repetitive, such as one derived from a repetitive laser. Once the pulse is found, it is an easy matter to reduce the pulse width and adjust the delay until the precise timing needed is achieved. The PI-MAX4 repetitive and sequential gating can be used to good advantage in this method.

Example

This example is simplified in that it does not address all of the possible settings for Gate mode setup. It is intended as a sense of how to locate the signal of interest by successively decreasing gate pulse parameters.

1. Starting with a 1 µs gate and delay set to the minimum value for the PI-MAX4 (~25 ns,) the pulse is located. It is then known that the pulse arrives sometime between 25 ns and 1.025 µs.

WinX	LightField
 Number of Images/Spectra: 1	**Gate Mode**: Repetitive **Number of Frames**: 1 **Gate Delay**: 25 ns **Gate Width**: 1 µs

2. Next, set the sequential gating parameters for 20 ns gate width and 101 images/spectra {frames} at 10 ns per image/spectra {frames}. This swill pan the 1 μs. The starting gate delay is set to 25 ns, the ending gate delay is set to 1025, and take the sequence. We can then quickly look through the images or spectra (in LightField or WinX) and determine to the nearest 10 ns when the optical pulse arrived.

WinX	LightField
Number of Images/Spectra: 101	**Gate Mode**: Sequential **Number of Frames**: 101 **Starting Gate Delay**: 25 ns **Starting Gate Width**: 20 ns **Ending Gate Delay**: 1025 ns **Ending Gate Width**: 20 ns **Reported Gate Delay Increment**: 10 ns

3. Assuming we found the signal in frame 12, we now set a narrower gate (e.g., 3 ns,) and sweep about this value in 500 ps steps with a span of 60 ns to find the time within 500 ps. Adjust the experiment for best signal strength and/or signal to noise ratio, then jump down to the final gate width (if width < 500 ps is desired) and again do a sweep to find the exact timing that maximizes the result. This method has the advantage of assuring that the camera is seeing the pulse with the most favorable set-up before narrowing the gate width down.

WinX	LightField
Number of Images/Spectra: 121	**Gate Mode**: Sequential **Number of Frames**: 121 **Starting Gate Delay**: 116 ns **Starting Gate Width**: 3 ns **Ending Gate Delay**: 176 ns **Ending Gate Width**: 3 ns **Reported Gate Delay Increment**: 0.5 ns

Chapter 13: PI-MAX4: 1024i-RF and RF Modulation

The unique features of the PI-MAX4: 1024i-RF camera and LightField (Princeton Instruments 64-bit software) allow researchers to quickly and easily create experimental setups for Frequency domain or Time domain fluorescence lifetime measurements. The PI-MAX4: 1024i-RF packs two camera capabilities in one. For Frequency domain measurements, it has built-in RF modulation electronics to modulate the image intensifier and independent electronics to provide a modulated output signal that can drive a light source or any other component in the experiment that requires modulation. Not only that, it still has all the standard features of fast (~ 2 ns) gating for Time domain measurements. Additionally, the camera's interline CCD with 1024 x 1024 pixels allows one to take two images within a <500 ps interval (DIF feature.)

13.1 Basics of RF Modulation on Intensified CCDs

The RF Modulation technique uses an RF source to vary the intensifier gain of an intensified CCD (ICCD) at a radio frequency (RF) rate. Usually, the object under study is illuminated by a light source which also varies at an RF rate, equal (homodyne technique) to the rate at which the intensifier gain is varied. The signal delivered from the intensifier to the CCD (within the ICCD) is the product of the intensifier gain and input light intensity. Consequently, the signal contains (among other components) the product of the two RF sine waves (light source RF and intensifier RF.) So the modulated ICCD behaves as an imaging lock-in amplifier, with the CCD acting as the output low pass filter.

Some of the advantages of the imaging lock-in are increased sensitivity, ability to measure phase shifts and time constants which would be difficult to measure using only gating techniques, and the ability to do this with low peak power illumination. These cameras can be used for Fluorescence Lifetime Imaging (FLIM,) Fluorescent Resonant Energy Transfer (FRET,) single molecule fluorescence and other studies in which the illumination must be limited in order to prevent sample destruction by the incident light.

The homodyne technique is perhaps the best and easiest to use with the PI-MAX4: 1024i-RF. In this technique, both the light and the intensifier are modulated at the same frequency, and the (relative) phase is stepped for each image. Thus, once a set of images at a given frequency is acquired, one may easily (given adequate software for all the computational work) determine the phase shift of the sample at the set frequency. If this is done at number of frequencies, one then has the measured complex frequency response of the sample. This response can be transformed into the time domain using the Inverse Fourier Transform.

13.2 Advantages of PI-MAX4: 1024i-RF

Classically, the experimenter wishing to use the RF technique had to collect and interconnect and control various devices, including the ICCD itself, one or two RF sources, two (usually) RF power amplifiers, a light source and a modulator. With the PI-MAX4: 1024i-RF, the two RF sources and one RF amplifier are integrated in the ICCD. This saves time, money, bench space and complexity. Coordination between the RF and the camera actions is built in. The RF sources are direct digital synthesizers (DDSs) so the generated RF is very precise in frequency and phase. The user still needs to provide a light source capable of RF Modulation and possibly an RF amplifier matched to the needs of the user's light source. As many light sources are feasible, the PI-MAX4: 1024i-RF was designed with a low level RF output for the user's convenience. It can drive most commercially available RF amplifiers.

The PI-MAX4: 1024i-RF is capable of executing RF sequences, much like the gate sequences in the PI-MAX4. In fact, the RF sequence works in conjunction with the gate sequence so that the RF is on during the time the PI-MAX4: 1024i-RF is capturing light, and off during the reading of the CCD. For those using the homodyne technique, this makes operation simple and convenient. Once the user selects a set of phase shifts and frequencies, these can be loaded into the camera so that the camera can execute them at the highest rate, limited only by the exposure time per image, the readout time, and the phosphor decay time. The frequency and phase points can be in any order; they are not required to be in a strictly ascending or descending order. This means that once the exposure of the sample starts, the data will be measured in the minimum time, thereby minimizing sample degradation due to the illumination.

NOTE:

The PI-MAX4: 1024i-RF does not support picosecond gating nor MCP gating.

Figure 13-1: System Diagram: RF Operation
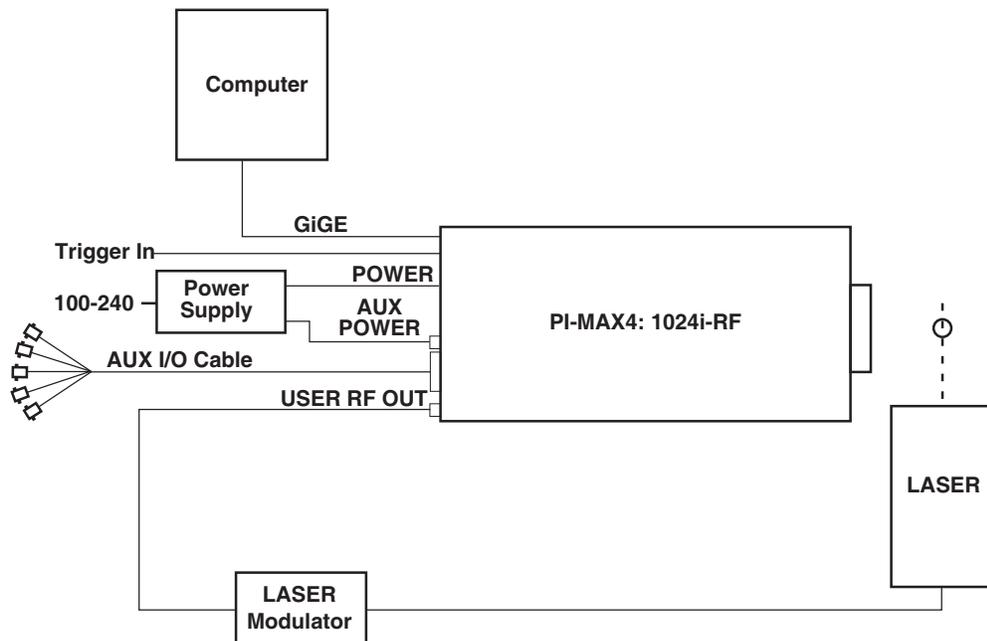
SPECTROGRAPH, COOLANT CIRCULATOR, AND DRY NITROGEN TANK CONNECTIONS ARE OPTIONAL AND ARE NOT SHOWN IN THIS DIAGRAM.

4411-0137_0113

13.3   RF Experiment Design in LightField

> **NOTE:**
>
> When launching LightField, click on the **New Experiment** icon. When the PI-MAX4: 1024i-RF icon is moved to the **Experiment Devices** area, the camera's default settings will be active for the **Experiment Settings** stack. At some point in the setup process, save the experiment via the **Save Experiment** icon or the F4 key.

13.3.1   Requirements

For RF operation, the PI-MAX4 must have RF capability and **Use RF Modulation** must be selected on the **Common Acquisition Settings** expander.

13.3.2   Trigger Response

Triggering for RF operation is set up on the LightField **Trigger** expander. The trigger can either be internally generated by the PI-MAX4: 1024i-RF or can be generated by an external source connected to the TRIGGER IN connector on the rear of the camera.

The trigger source is selectable via the **Trigger Source** drop-down list, where the following options are available:

- **Internal**
  Trigger pulses are generated by the PI-MAX4: 1024i-RF based on the **Internal Trigger Frequency** setting which is configured on the **SuperSYNCHRO Timing** panel.
  The range of trigger frequencies is 2 Hz to 1 MHz, in 1 Hz increments.

> **NOTE:**
>
> The **Internal Trigger Frequency** setting also determines the frequency of **SyncMASTER1** and **SyncMASTER2** outputs on the AUX I/O cable.

- **External**
  In order for the PI-MAX4: 1024i-RF to recognize triggers from an external source, the characteristics of the triggers to be supplied must be provided. These characteristics include are configured on the **Trigger** expander, and include:
  — Trigger Threshold;
  — Coupling;
  — Termination;
  — Polarity.

13.3.3 Gating Mode

LightField supports three Gating modes for RF experiments:

- Repetitive;
- Sequential;
- Custom.

The desired option is selected from the **Gating Mode** drop down list on the **SuperSYNCHRO Timing** panel. Each mode has its own set of configuration parameters which are described in the following sections.

13.3.3.1 Repetitive

Perform the following procedure to configure Repetitive Gating Mode:

1. The first requirement is that the PI-MAX4: 1024i-RF camera be aligned and focused on the area of interest in the experiment. This is best accomplished while the camera is operating in Full Frame readout mode. Verify that the **Phosphor Decay Delay** is appropriate to the phosphor used by your camera: the phosphor decay delay time entered in LightField can be viewed or changed after clicking on the **Advanced** button on the **Common Acquisition Settings** expander. The procedure for initial focus is described in Chapter 4, First Light.

> **NOTE:**
>
> The **Phosphor Decay Delay** setting tells LightField how long to wait after the gate pulse to shift the image. If there is some residual image from the first frame in the second frame, simply increase the **Phosphor Decay Delay** setting to allow more time for the phosphor emission to decay before shifting the image.

2. After the alignment and focus, the PI-MAX: 1024i-RF system needs to be put into RF modulation mode. On the **Common Acquisitions Settings** expander, select **Use RF Modulation**.

3. On the **Trigger** expander, select Internal or External triggering.
   - For External triggering, make sure the trigger characteristics on the **Trigger** expander match the active trigger edge, etc. of the trigger pulse that will be used.
   - For Internal triggering, set the **Internal Trigger Frequency** on the **SuperSYNCHRO Timing** expander.

4. Open the **SuperSYNCHRO Timing** expander (at the bottom of the window.) See Figure 13-2.

Figure 13-2: SuperSYNCHRO Timing Expander: Repetitive Gating Mode
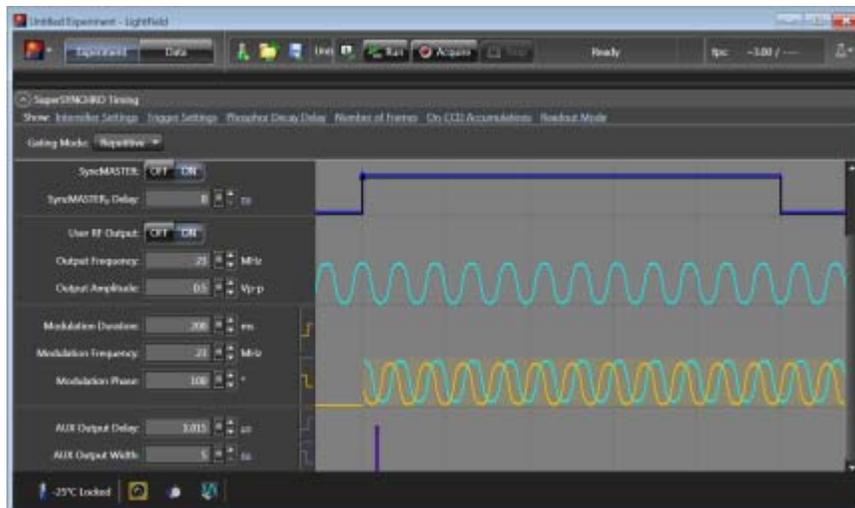
4411-0137_0114

5. Select **Repetitive** as the Gating Mode and begin entering the setup information.

6. Use the hyperlinks at the top of the expanded panel to make any changes to the intensifier settings, trigger settings, phosphor decay delay time, number of frames, and readout mode.

7. When using camera-generated internal triggers for RF modulation acquisition, enter the desired **Internal Trigger Frequency**.

8. To have trigger output from the **SyncMASTER1** and **SyncMASTER2** connectors on the AUX I/O cable, click on the **SyncMASTER ON** button. When **SyncMASTER** is enabled, the output of the **SyncMASTER1** connector will be at the **Internal Trigger Frequency**. The **SyncMASTER2** output will be at the same frequency but can be delayed. The available range for this delay is 0 to 6553500 ns in 100 ns increments.

> **NOTE:**
>
> The blue SyncMASTER1 and black of SyncMASTER2 cables are used to differentiate these output signals when they are shown on the SuperSYNCHRO timing diagram.

9. Enter the **Modulation Duration**, **Modulation Frequency**, and **Modulation Phase** values.

10. To drive an RF amplifier via the **User RF Out** connector on the back of the PI-MAX4: 1024i-RF, click on the **User RF Output ON** button. Then select the appropriate frequency and amplitude level (V_{p-p}.) Note that the **User RF Output** must be connected to a 50 Ω load (standard for RF.)

11. If required, set up **AUX Output** trigger.

12. Verify that the **I.I.T. Power** switch on the rear of the PI-MAX4: 1024i-RF is turned **ON** and **Enable Intensifier** has been checked on the **Common Acquisition Settings** expander.

13. When the experiment is ready, click on the **Acquire** button.

13.3.3.2 *Sequential*

Perform the following procedure to configure Sequential Gating Mode:

1. The first requirement is that the PI-MAX4: 1024i-RF camera be aligned and focused on the area of interest in the experiment. This is best accomplished while the camera is operating in Full Frame readout mode. Verify that the **Phosphor Decay Delay** is appropriate to the phosphor used by your camera: the phosphor decay delay time entered in LightField can be viewed or changed after clicking on the **Advanced** button on the **Common Acquisition Settings** expander. The procedure for initial focus is described in Chapter 4, First Light.

> **NOTE:**
>
> The **Phosphor Decay Delay** setting is used to tell LightField how long to wait after the gate pulse to shift the image. If there is some residual image from the first frame in the second frame, simply increase the Phosphor Decay Delay setting to allow more time for the phosphor emission to decay before shifting the image.

2. After the alignment and focus, the PI-MAX: 1024i-RF system needs to be put into RF modulation mode. On the **Common Acquisitions Settings** expander, select **Use RF Modulation**.

3. Enter 2 or more in the **Number of Frames** field. The range is 2 to 1,023.

4. To track the modulation phase, click in the **Modulation Tracking** check box.

5. On the **Trigger** expander, select Internal or External triggering.

   - For External triggering, make sure the trigger characteristics on the **Trigger** expander match the active trigger edge, etc. of the trigger pulse that will be used.

   - For Internal triggering, set the **Internal Trigger Frequency** on the **SuperSYNCHRO Timing** expander.

6. Open the **SuperSYNCHRO Timing** expander (at the bottom of the window.) See Figure 13-3.

Figure 13-3: SuperSYNCHRO Timing Expander: Sequential Gating Mode
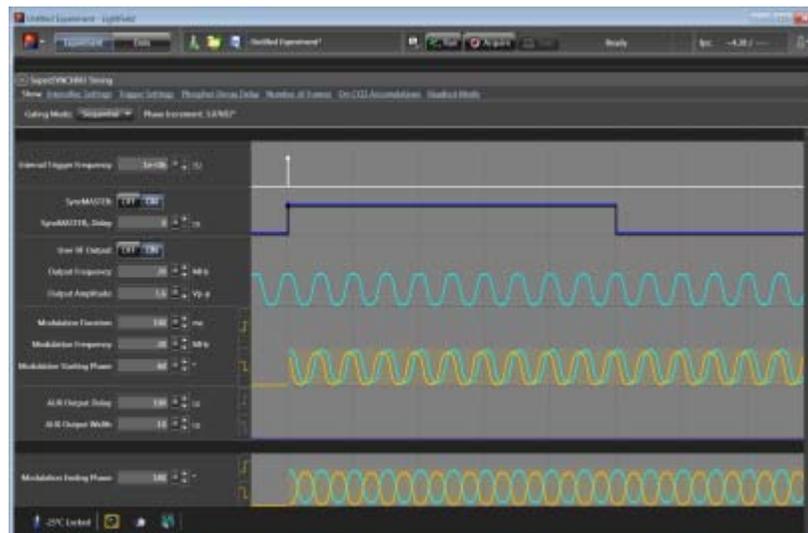
4411-0137_0115

7. Select **Sequential** as the Gating Mode and begin entering the setup information.

8. Use the hyperlinks at the top of the expanded panel to make any changes to the intensifier settings, trigger settings, phosphor decay delay time, number of frames, and readout mode.

9. When using camera-generated internal triggers for RF modulation acquisition, enter the desired **Internal Trigger Frequency**.

10. To have trigger output from the **SyncMASTER1** and **SyncMASTER2** connectors on the AUX I/O cable, click on the **SyncMASTER ON** button. When **SyncMASTER** is enabled, the output of the SyncMASTER1 connector will be at the **Internal Trigger Frequency**. The SyncMASTER2 output will be at the same frequency but can be delayed. The available range for this delay is 0 to 6553500 ns in 100 ns increments.

> **NOTE:** ────────────────────────
>
> The blue SyncMASTER1 and black SyncMASTER2 cables are used to differentiate these output signals when they are shown on the SuperSYNCHRO timing diagram.

11. Enter the **Modulation Duration**, **Modulation Frequency**, and **Modulation Starting Phase** values.

12. To drive an RF amplifier via the **User RF Out** connector on the back of the PI-MAX4: 1024i-RF, click on the **User RF Output ON** button. Then select the appropriate frequency and amplitude level (V_{p-p}.) Note that the **User RF Output** must be connected to a 50 Ω load (standard for RF.)

13. If required, set up **AUX Output** trigger.

14. Enter the **Modulation Ending Phase**. You may need to scroll down.

15. Verify that the **I.I.T. Power** switch on the rear of the PI-MAX4: 1024i-RF is turned **ON** and that **Enable Intensifier** has been checked on the **Common Acquisition Settings** expander.

16. When the experiment is ready, click on the **Acquire** button.

13.3.3.3 Custom

Perform the following procedure to configure Custom Gating Mode:

1. The first requirement is that the PI-MAX4: 1024i-RF camera be aligned and focused on the area of interest in the experiment. This is best accomplished while the camera is operating in Full Frame readout mode. Verify that the **Phosphor Decay Delay** is appropriate to the phosphor used by the camera: the phosphor decay delay time entered in LightField can be viewed or changed after clicking on the **Advanced** button on the **Common Acquisition Settings** expander. The procedure for initial focus is described in Chapter 4, First Light.

> **NOTE:**
>
> The **Phosphor Decay Delay** setting is used to tell LightField how long to wait after the gate pulse to shift the image. If there is some residual image from the first frame in the second frame, simply increase the **Phosphor Decay Delay** setting to allow more time for the phosphor emission to decay before shifting the image.

2. After the alignment and focus, the PI-MAX: 1024i-RF system needs to be put into RF modulation mode. On the **Common Acquisitions Settings** expander, select **Use RF Modulation**.

3. On the **Trigger** expander, select **Internal** or **External** triggering.

    - For External triggering, make sure the trigger characteristics on the **Trigger** expander match the active trigger edge, etc. of the trigger pulse that will be used.
    - For Internal triggering, set the **Internal Trigger Frequency** on the **SuperSYNCHRO Timing** expander.

4. Open the **SuperSYNCHRO Timing** expander. See Figure 13-4.

Figure 13-4: SuperSYNCHRO Timing Expander: Custom Gating Mode

4411-0137_0160
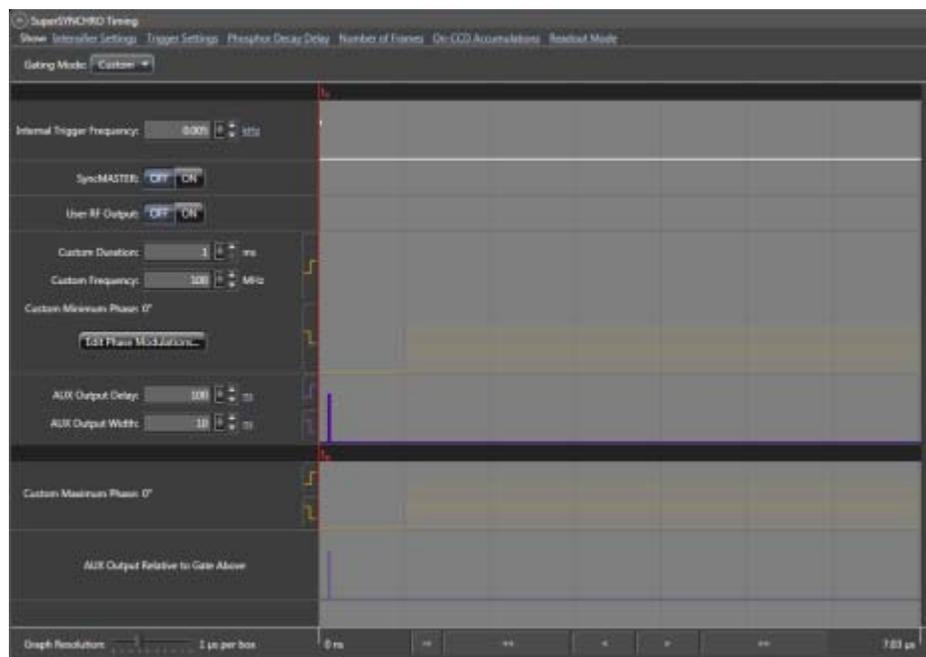
5. Use the hyperlinks at the top of the expanded panel to make any changes to the intensifier settings, trigger settings, phosphor decay delay time, number of frames, and readout mode.

6. If using camera-generated internal triggers for RF modulation acquisition, enter the desired **Internal Trigger Frequency**.

7. To have trigger output from the **SyncMASTER1** and **SyncMASTER2** connectors on the AUX I/O cable, click on the **SyncMASTER ON** button. When **SyncMASTER** is enabled, the output of the **SyncMASTER1** connector will be at the **Internal Trigger Frequency**. The **SyncMASTER2** output will be at the same frequency but can be delayed. The available range for this delay is 0 to 6553500 ns in 100 ns increments.

> **NOTE:**
>
> The blue SyncMASTER1 and black SyncMASTER2 cables are used to differentiate these output signals when they are shown on the SuperSYNCHRO timing diagram.

8. Perform the following procedure to edit/create the custom Phase Modulation table:

   a. Click on the **Edit Phase Modulations…** button to display the **Edit Custom Phase Modulations** dialog similar to that shown in Figure 13-5.

Figure 13-5: Typical Edit Custom Phase Modulations Window

4411-0137_0161
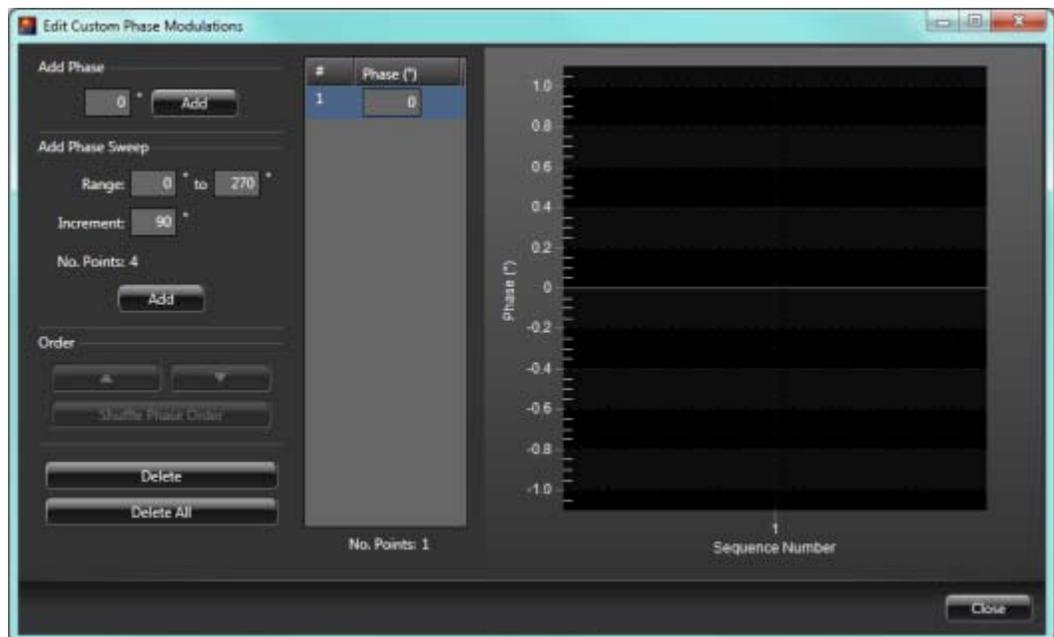
   b. To add a single point to the table, within the **Add Phase** section, enter the desired
   modulation, in degrees, and click **Add**.

   The point is added to the table. See Figure 13-6.

Figure 13-6: Add a Single Modulation Phase

4411-0137_0162
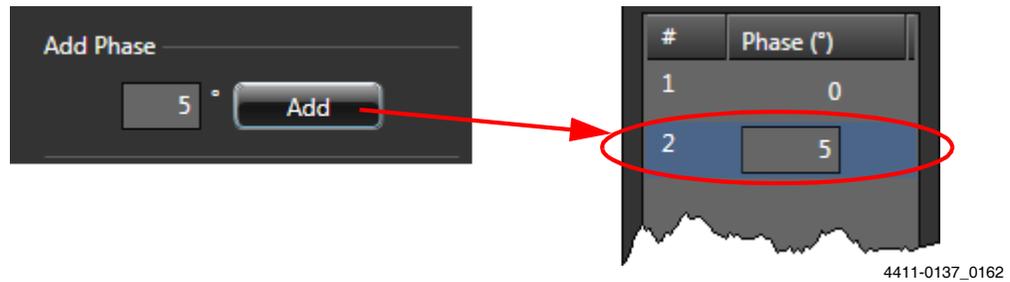
   Additional points may be added as necessary.

   c. To add a phase sweep, within the **Add Phase Sweep** section, configure the
   following parameters:

   • Enter the desired modulation **Range**, in degrees, by specifying the Start Range
     and End Range values.

     Valid values for the Start/End Ranges are -36000 … +36000.

     In addition:

     — If Start Range < End Range, the sweep proceeds in a positive/
       counterclockwise direction.

     — If End Range < Start Range, the sweep proceeds in a negative/clockwise
       direction.

   • Enter the desired **Increment**, in degrees, between successive points along the
     sweep.

     An appropriate Increment value must be chosen such that when stepping from
     the Start Range through to the End Range, the result is a whole number of steps.

   NOTE: ─────────────────────

   LightField automatically calculates, and displays, the number
   of points to be added based on the **Range** and **Increment**
   values used. If the result is not a whole number of steps, an
   error message is displayed.

   ─────────────────────

   Although Start/End Range values up to ±36000° (inclusive) are valid, the specified
   range will be converted/shifted to a standard [0 … 359] degree scale, and the
   corresponding number of points will be added to LightField. Once any sweep in
   excess of 359° reaches the 360° mark, it "returns" to zero and continues sweeping
   through the next 359°. The sweep continues in this manner until it has swept
   through the entire range.

Example

The following Phase Sweep values have been configured:

- **Range Start:** -720°
- **Range End:** +360°
- **Increment:** 90°

The total sweep length is 1080° in 90° increments/steps which corresponds to 13 data points. Since Range Start < Range End, the sweep proceeds in a positive/counterclockwise direction.

LightField "shifts" the programmed sweep starting point so that it starts at 0°.

Table 13-1 shows the corresponding/calculated values for each step in the sweep.

Table 13-1: Phase Sweep Information for Sweep > 360°

Phase Table Step	Phase Table Value	Programmed Phase Angle	Cumulative Sweep Total	Increment
1	0°	-720° [Range Start]	0°	90°
2	90°	-630°	90°	90°
3	180°	-540°	180°	90°
4	270°	-450°	270°	90°
5	0°	-360°	360°	90°
6	90°	-270°	450°	90°
7	180°	-180°	540°	90°
8	270°	-90°	630°	90°
9	0°	0°	720°	90°
10	90°	90°	810°	90°
11	180°	180°	900°	90°
12	270°	270°	990°	90°
13	0°	360° [Range End]	1080°	90°

d. Once the Range and Increment have been configured, click **Add** to add the points to the table. See Figure 13-7.

Figure 13-7: Add Phase Sweep
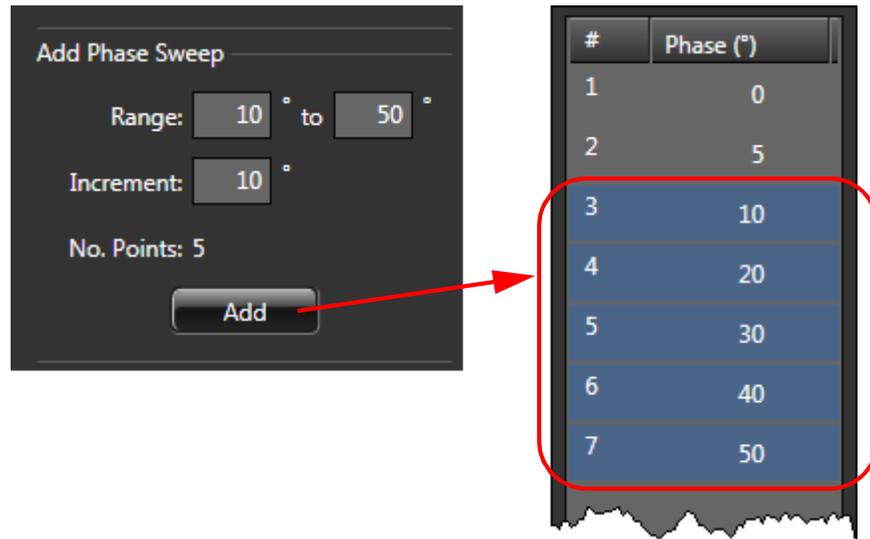
4411-0137_0163

Depending on the total number of points within the table, LightField will raise an **Experiment Warning** if the number of frames that has been configured on the **Common Acquisition Settings** expander is:

• Less than the total number of points in the table; or

• Not a whole multiple of the total number of points in the table.

The Experiment Warning will be dismissed when the number of frames is changed and satisfies the above criteria.

NOTE:

> Although the Experiment Warning will not prevent an experiment from being run, depending on the settings, incomplete data may be collected/returned.
>
> For example, if the total number of points in the table is 15, and the number of frames is 7, data will be collected/returned only for the first 7 points within the table, leaving 8 data points untested.

e. The shape of the resulting modulation phase curve is displayed to the right of the table. Figure 13-8 illustrates a typical curve.

Figure 13-8: Typical Modulation Phase Curve
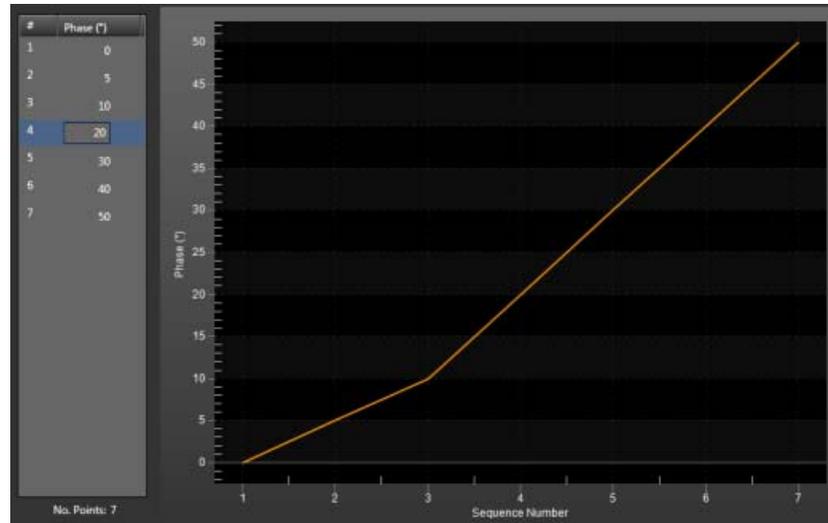
4411-0137_0164

f. Points that comprise the curve can be rearranged/reordered as follows:

- The set of points can be sorted in ascending or descending order by clicking on the **Phase (°)** column header;

- Individual points can be shifted up or down within the table by selecting them and then clicking the ▲ and ▼ buttons until they are in the desired location;

> 🔍 **NOTE:**
>
> Two or more adjacent points may be selected and shifted as a group. Non-adjacent points must be moved individually.

- All points can be randomized by clicking the **Shuffle Phase Order** button.

The Phase Curve updates automatically as the order of the points within the table is modified. Figure 13-9 illustrates a curve where all seven (7) points have been shuffled.

Figure 13-9: Typical Modulation Phase Curve with Points Shuffled
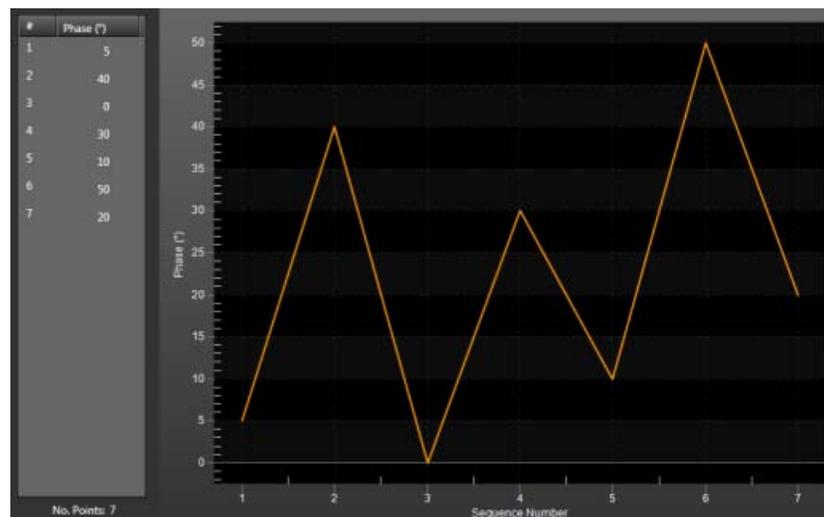
4411-0137_0165

g. Points may be deleted from the table by selecting them (either individually or using CTRL-Click for multiple points) and then clicking **Delete**. To delete all points, click **Delete All**.

h. Once the custom Modulation Table is complete, click **Close** to save the table and dismiss the window.

9. Configure **Custom Duration** and **Custom Frequency** as required.

Configuration values for **Custom Duration** and **Custom Frequency** apply to ALL entries within the Custom Modulation Phase table.

Valid values are:

• **Custom Duration**: [1 ms … 21 s] inclusive, in 1 ms increments;

• **Custom Frequency**: [1 MHz … 200 MHz] inclusive, in 1 MHz increments.

> **NOTE:**
>
> If custom values are required on a per-Modulation-table-entry basis, a custom add-in must be developed and activated by the end user to provide this functionality.
>
> When such an add-in has been developed and activated, LightField assumes all custom modulation configuration is done from within the add-in, and therefore:
>
> • No **Custom Modulation Phase** table changes will be permitted within LightField;
>
> • No **Custom Duration** value will be displayed within LightField;
>
> • No **Custom Frequency** value will be displayed within LightField.
>
> Refer to document number 4410-0135, LightField Add-ins and Automation Programming, for information about developing custom add-ins for LightField.

10. To drive an RF amplifier via the **User RF Out** connector on the back of the PI-MAX4: 1024i-RF, click on the **User RF Output ON** button.

> **NOTE:**
>
> The **User RF Output** must be connected to a standard 50 Ω RF load.

Configure **Custom Output Frequency** and **Output Amplitude** (V_{p-p}) as required.

11. If required, configure the following **AUX Output** parameters:

• **AUX Output Delay**;

• **AUX Output Width**.

12. Verify that the **I.I.T. Power** switch on the rear of the PI-MAX4: 1024i-RF is turned **ON** and that **Enable Intensifier** has been checked on the **Common Acquisition Settings** expander.

13. When the experiment is ready, click on the **Acquire** button.

13.3.4   Phase Modulation Sorting Add-In

When activated, this add-in provides the ability to sort SPE frames by Phase after each acquisition has been completed.

> 🔍 **NOTE:** _____
>
> Sorting SPE frames with the Phase Modulation Sorting add-in is non-destructive and preserves the original Phase order for the set of SPE frames.

In addition, SPE frames gathered and saved from a previous experiment can be sorted by phase as a post process once the add-in has been loaded.

Perform the following procedure to sort SPE frames by phase:

1.   Within LightField, click on **Application Menu —> Manage Add-ins…** to display the **Manage Add-ins** dialog. See Figure 13-10.

Figure 13-10:Typical Manage Add-ins Dialog
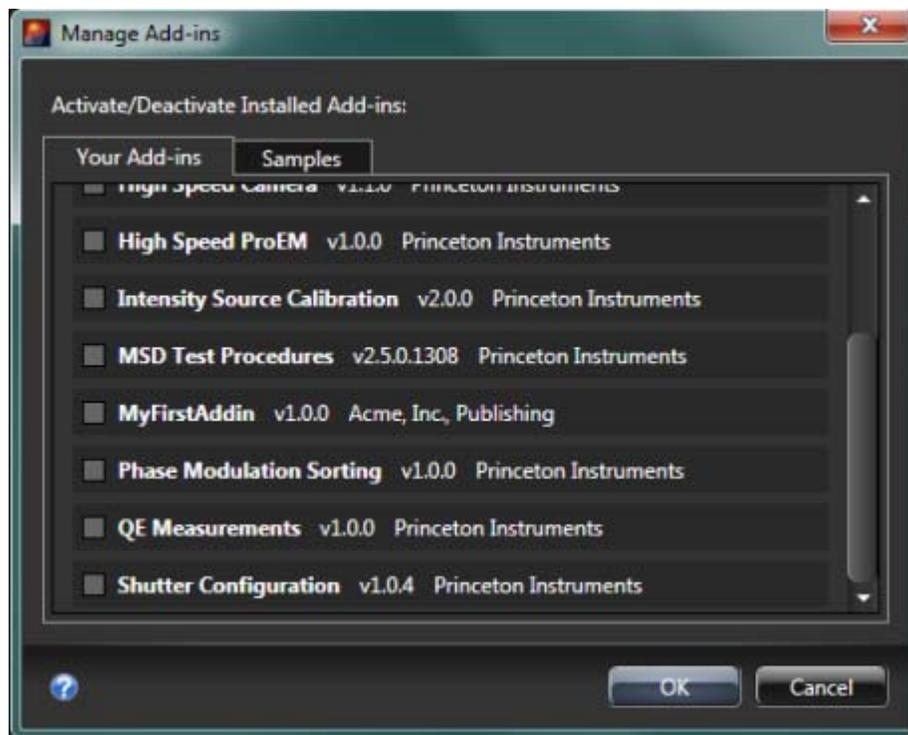
4411-0137_0166

2.   On the **Your Add-ins** tab, locate the **Phase Modulation Sorting** add-in and click on its box to select it.

3.   Click **OK** to activate the add-in and dismiss the dialog.

4. Perform the following procedure to sort SPE frames by phase after each acquisition:

   a. Click on the **Add-ins** tab and locate the **Phase Modulation Sorting** expander. If necessary, click on the ☑ to expand it. See Figure 13-11.

Figure 13-11:Typical Phase Modulation Sorting Add-in
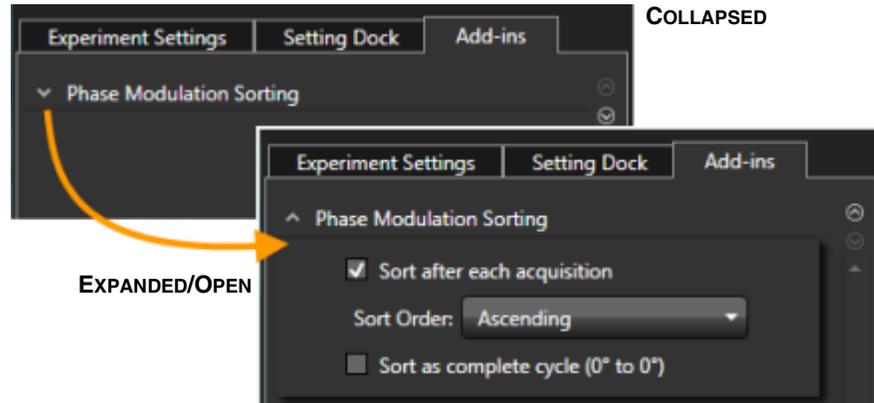
   b. Check the box next to **Sort after each acquisition**, and select the desired sort order from the pull-down list (i.e., **Ascending** or **Descending**.)

   c. If desired, check the box next to **Sort as Complete Cycle (0° to 0°.)** When checked, alternate 0 degree Phases will be treated as 360 degree points.

   d. Perform the experiment as usual, and two SPE files are saved for each acquisition. For example, the two files from an experiment could be named:

   - `2013 August 20 15_10_20.spe`
     This is the set of frames that have been sorted by Phase Modulation.
   - `2013 August 20 15_10_20-unsorted.spe`
     This is the original set of frames.

5. Perform the following procedure to sort SPE frames from a prior experiment:

   a. Within LightField, click on the **Data** tab.

   b. Locate and click on the **Sort Phases…** add-in button within the Data Toolbar. See Figure 13-12.

Figure 13-12:Typical Phase Modulation Sorting Add-in Button: Data Toolbar

The **Sort Phases** dialog is displayed, similar to that shown in Figure 13-13.

Figure 13-13:Typical Sort Phases Dialog
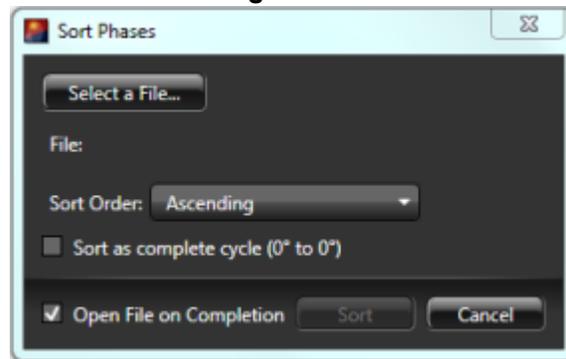
4411-0137_0169

c. Click on **Select a File…**, navigate to, and select the desired SPE file. Click **Open**. The name of the selected file will be shown in the **File:** field. See Figure 13-14.

Figure 13-14:Typical Sort Phases Dialog: SPE File Specified
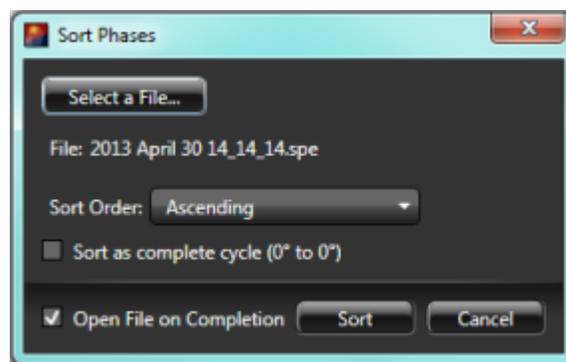
4411-0137_0170

d. Select the desired **Sort Order** from the pull-down list (i.e., **Ascending** or **Descending**.)

e. To view the sorted data, check the box next to **Open File on Completion**.

f. If desired, check the box next to **Sort as Complete Cycle (0° to 0°.)** When checked, alternate 0 degree Phases will be treated as 360 degree points.

g. Click **Sort**.

h. A new SPE file will be saved with the same name as the original file, but with -sorted appended.

   For example, using the file shown in Figure 13-14, the new file will be named 2013 April 30 14_14_14-sorted.spe.

6. To disable the add-in, click on **Application Menu —> Manage Add-ins…** to display the **Manage Add-ins** dialog.

7. On the **Your Add-ins** tab, locate the **Phase Modulation Sorting** add-in and click on its box to deselect it.

8. Click **OK** to deactivate the add-in and dismiss the dialog.

13.4   PI-MAX4: 1024i-RF Rear Panel Information

The rear panel of the PI-MAX4: 1024i-RF is illustrated in Figure 13-15 with connectors, indicators, and switches identified. Refer to Table 13-2 for complete descriptions and information.

REFERENCES:

Refer to Section 13.4.1, PI-MAX4: 1024i-RF Power Supply Rear Panel Information, on page 202 for corresponding information about the PI-MAX4: 1024i-RF Power Supply.

Figure 13-15:PI-MAX4: 1024i-RF Rear Panel

4411-0137_0116
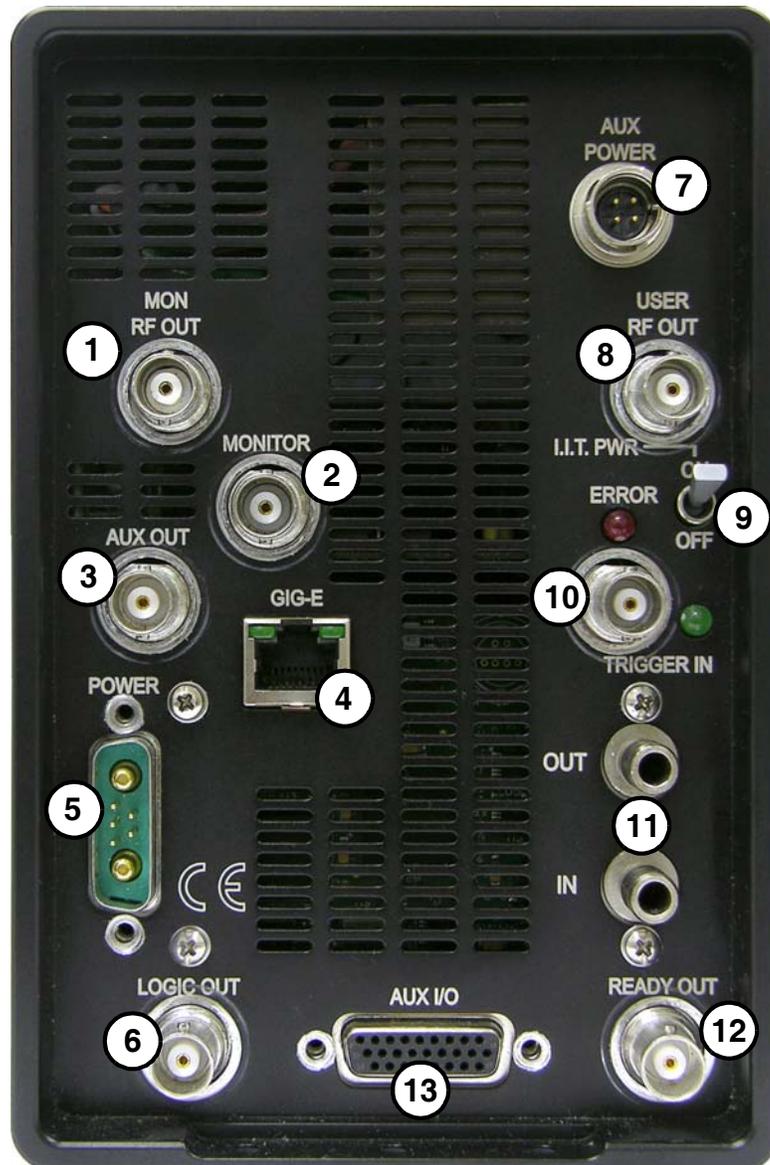
Table 13-2: PI-MAX4: 1024i-RF Connectors, Indicators, and Switches (Sheet 1 of 2)

#	Label	Description
1	MON RF OUT	Provides an approximate indicator of the user-defined RF applied to the photocathode.
2	MONITOR	Provides an output for TTL logic 1 pulse delayed ± 3 ns with respect to photocathode gating. Cable delay, ~1.5 ns/ft, will be in addition to the delay at the connector.
3	AUX OUT	DC-coupled variable delay trigger output for synchronizing other system components with the PI-MAX4: 1024i-RF internal timing generator. The host software sets the Delay Time of this output with respect to the internal timing generator trigger time. The source impedance is approximately 100 Ω and it will provide > 1 V into 50 Ω.
4	GIG-E	Gigabit Ethernet connector.
5	POWER	7-pin D specialty connector; connects to the PI-MAX4: 1024i-RF power supply. See Figure 13-15.
6	LOGIC OUT	0 to +3.3V logic level output (TTL-compatible.) WinX software-selectable Acquiring, Image Shift, Logic 1, Read Out, Shutter, and Wait for Trigger signal. When the Invert LOGIC check box is checked, the output is at a logic low when the action is occurring.
7	AUX POWER	Power input for the RF modulation section of the camera.
8	USER RF OUT	User-programmable continuous frequency output to synchronize external devices with PI-MAX4: 1024i-RF. When used, must be connected to a 50 Ω load (standard for RF.)
9	I.I.T. PWR	This switch biases the image intensifier photocathode ON or OFF. When the **I.I.T.** switch is set to **ON,** the photocathode can be gated ON. ***NOTE:*** In WinX, selecting **SAFE** on the **Experiment Setup —> Main** dialog overrides control and prevents the photocathode from being biased on regardless of the I.I.T. switch setting. In LightField, this override is done by unchecking the **Enable Intensifier** check box on the **Common Acquisition Settings** expander. When the I.I.T. switch is set to **OFF**, the photocathode cannot be turned on from software. It is advisable to turn the I.I.T. switch to its **OFF** position as a fail-safe measure if the PI-MAX4: 1024i-RF remains **ON** but unused for a period of time.
10	TRIGGER IN	When external triggering is selected in the software, the internal timing generator will be triggered by an externally derived trigger pulse (range of ±5.5 V) applied to this input. The threshold, slope, coupling mode (i.e., AC or DC,) and input impedance (i.e., High or 50 W,) are selectable in software. The associated Green LED flashes each time PI-MAX4: 1024i-RF is triggered (glows steadily at high repetition rates.) In gated operation, the green LED indicator flashes each time the PI-MAX4: 1024i-RF is triggered. The actual triggering can also be readily determined by observing the signal at the **Monitor** output with a fast oscilloscope.
11	**IN** and **OUT**	Standard ¼-inch barbed brass fitting for circulating coolant located on the back panel. Either port may be used as the inlet. **The coolant must not be chilled.** Use the Princeton Instruments CoolCUBE$_{II}$ coolant circulator. Refer to Section 3.7, Connect the Circulator [Liquid-Cooled Cameras Only], on page 42, for complete information.
12	READY OUT	The output level at this BNC is normally LOW. It changes state on completion of cleaning cycles before the first exposure

Table 13-2: PI-MAX4: 1024i-RF Connectors, Indicators, and Switches (Sheet 2 of 2)

#	Label	Description
13	AUX I/O	26-pin male DB connector. Provides five I/O signals that can be used to input a trigger to initiate data acquisition, monitor frame readout status, and/or control an external shutter. The five I/O signals are: • T0 Out; • Pre-Trigger In; • SyncMASTER1; • General Purpose Input 0; • SyncMASTER2. Refer to Section A.6, AUX I/O Interface, on page 258, for additional information.

13.4.1 PI-MAX4: 1024i-RF Power Supply Rear Panel Information

The rear panel of the PI-MAX4: 1024i-RF Power Supply is illustrated in Figure 13-16 with connectors, indicators, and switches identified. Refer to Table 13-3 for complete descriptions and information.

> 📖 **REFERENCES:**
>
> Refer to Section 13.4, PI-MAX4: 1024i-RF Rear Panel Information, on page 200 for corresponding information about the PI-MAX4: 1024i-RF camera.

Figure 13-16:PI-MAX4: 1024i-RF Power Supply Rear Panel

4411-0137_0117

Table 13-3: PI-MAX4: 1024i-RF Power Supply Connectors, Indicators, and Switches

#	Item	Description
1	Power Indicator	LED turns bright green when power switch (item #5) is turned on.
2	Tec Fault Indicator	LED turns bright red when a Temperature Control fault is detected.
3	PI-MAX4: 1024i-RF Power	7-pin D connector. Connects to the PI-MAX4: 1024i-RF camera.
4	RF Module Power	Power output for the RF modulation section of the camera.
5	AC Power Switch	On/Off toggle switch for incoming AC power (via item #6.) • **O** = Off • **I** = On
6	AC Power Input	Connects the Power Supply to an external AC receptacle using a standard AC cable.

13.5   RF Modulator Specifications

Modulation Frequency: 1 MHz – 200 MHz in 1 MHz increments.

Phase Modulation:

- Static phase: 0° – 359° in 1° increments
- Programmed sweeps covering >360°

User RF Output Voltage: 0.1 – 1.6 V_{p-p} (in 0.01 V_{p-p} increments)

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Chapter 14: PI-MAX4: EM Family

The PI-MAX4: EM family of scientific intensified EMCCD (emICCD) camera systems features frame transfer EMCCDs that are fiber-optically coupled with a variety of Gen II and Gen III filmless intensifiers.

> **NOTE:**
>
> WinX provides limited support of advanced PI-MAX4: EM features. LightField should be used in order to use all features available on the PI-MAX4: EM camera. Therefore, all procedures within this chapter are LightField-specific.

The intensifiers offer the highest available sensitivity from UV through NIR. The dual-gain mechanism (unique to these cameras) with optional picosecond gating capability and an integrated programmable timing generator (SuperSYNCHRO) built into the camera make these **em**ICCD cameras ideal for photon counting, time-resolved imaging and spectroscopy applications. PI-MAX4: EM cameras are the only emICCD cameras in the market today to offer both high frame rate at 10MHz/16-bit digitization, 1 MHz sustained gating repetition rate and exceptional sensitivity.

In addition to the standard suite of features and modes, the PI-MAX4:EM family of cameras can easily be configured to operate in the following modes:

- emICCD Mode;
- ICCD Mode;
- Photon Counting – Thresholding Mode;
- Integration – Clipping Mode,
- Kinetics Mode.

14.1   Electron Multiplication

Electron Multiplication (EM) is a sensitivity enhancing technique for CCDs that utilizes a specialized frame transfer CCD known as an Electron-Multiplying CCD (EMCCD.) Within its array, an EMCCD includes a second, extended serial register (typically called a **Multiplication Register**) through which electrons travel while having a higher than normal CCD clock voltage applied. Secondary electrons are then released within the register's silicon as a result of impact ionization.

The block diagram in Figure 14-1 illustrates this dual serial output register configuration.

Figure 14-1: Block Diagram: EMCCD with Dual Output Registers
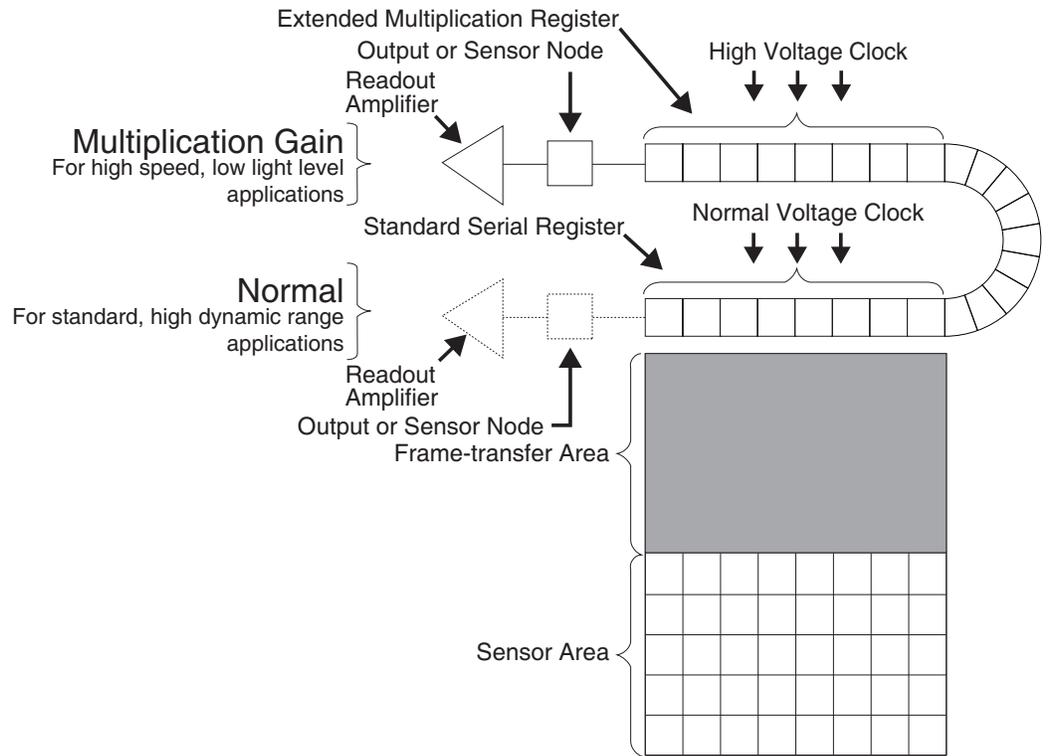
4411-0137_0118

The degree of multiplication gain is controlled by increasing or decreasing the clock voltages for the multiplication register (gain is exponentially proportional to the voltage.) Although the probability of generating secondary electrons is fairly low (i.e., typically 0.01 per stage,) over the large number of stages within a typical multiplication register, the total gain can be quite high.

> **NOTE:**
>
> Because on-chip multiplication introduces additional noise, it is recommended that the multiplication be used only as required.

PI-MAX4: EM cameras combine an EMCCD with standard intensifiers to provide an additional gain stage for increased sensitivity in extremely low-light applications. This combination is referred to as emICCD.

Figure 14-2 illustrates a typical emICCD hardware stack.

Figure 14-2: Typical emICCD Hardware Stackup
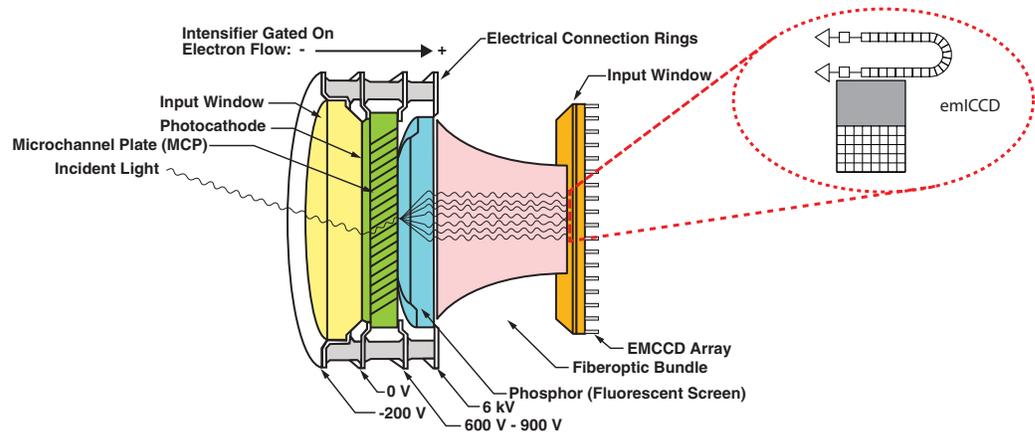
4411-0137_0119

14.1.1 Enabling EM

Electron Multiplication is enabled on the **Analog to Digital Conversion** expander by selecting **Electron Multiplied** from within the **Quality** field. See Figure 14-3.

Figure 14-3: Enabling Electron Multiplication
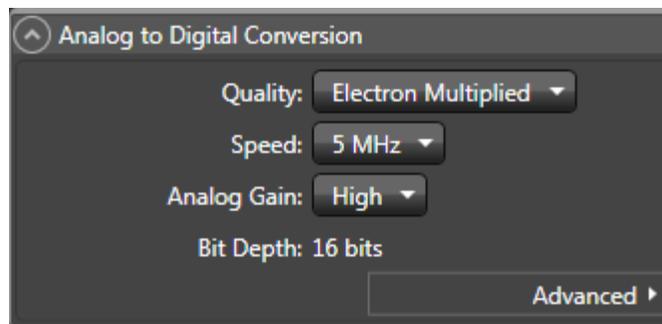
4411-0137_0120

Once enabled, several additional configuration options become active which may require customization based on specific experiment requirements.

14.1.2 EM Gain Mode

In EM Gain mode, the PI-MAX4: EM family supports two additional modes of operation (i.e., Optimal and Manual.) Depending on the specific mode selected, the available set of mode-specific configuration parameters is automatically updated within LightField.

14.1.2.1 *Optimal*

This is the default mode and is recommended for most applications.

In Optimal mode, camera gain is set by configuring only one parameter, **emICCD Gain** which is located on the **Common Acquisition Settings** expander as part of the **Intensifier** configuration settings block. SeeFigure 14-4.

Figure 14-4: Typical emICCD Gain Configuration Field
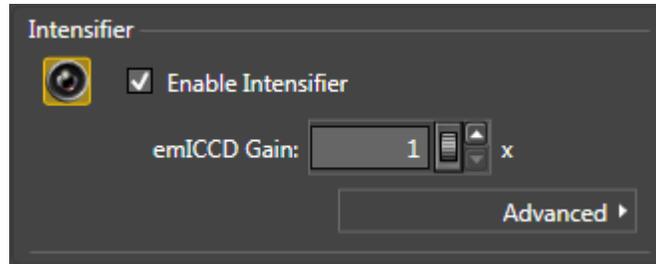
4411-0137_0121

The desired gain may be specified manually using the keyboard, or adjusted using the scroll wheel and/or the Up/Down arrows provided.

Valid gain settings are whole numbers between 1 and 10,000 (inclusive,) where:

- 1x corresponds to no gain and the camera performs as a standard high-speed CCD with rather high read noise.
- 10000x is the maximum gain setting.

Gain values are mapped non-linearly to the internal serial clock voltages that vary the multiplication gain resulting in an approximate 1:1 relationship between desired/configured gain setting and actual gain.

Once a value for emICCD Gain has been selected, LightField then uses a complex algorithm to automatically select the best combination/ratio of Intensifier and EM gain values to provide the best possible signal-to-noise ratio.

14.1.2.2 Manual

In Manual mode, Intensifier gain and EM gain must both be individually configured and controlled.

- **Intensifier Gain** is configured on the **Common Acquisition Settings** expander. Figure 14-5 shows the **Intensifier Gain** configuration fields available for Manual Mode.

Figure 14-5: Typical Intensifier Gain Configuration Fields
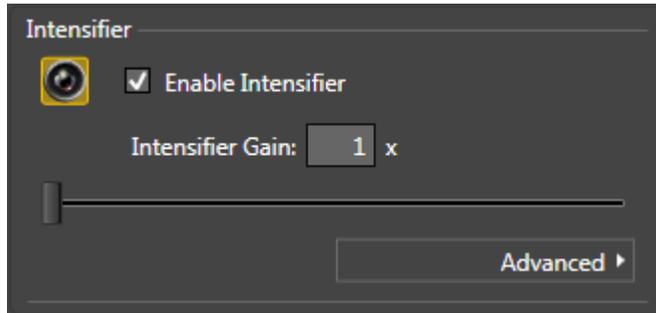
4411-0137_0122

The desired Intensifier Gain can be specified manually using the keyboard, or adjusted using the slider bar located just below the field.

Valid Intensifier Gain values are whole numbers from 1x to 100x, inclusive.

- **EM Gain** is configured on the **Analog to Digital Conversion** expander. Figure 14-6 shows the EM Gain configuration fields available for Manual Mode.

Figure 14-6: Typical EM Gain Configuration Field
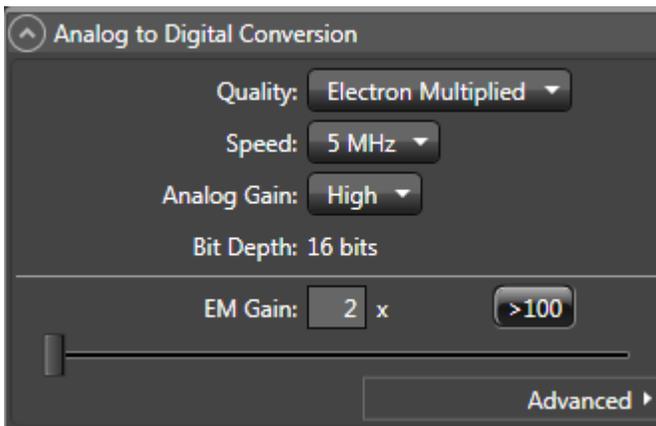
4411-0137_0123

The desired EM Gain can be specified manually using the keyboard, or adjusted using the slider bar located just below the field.

Recommended EM Gain values are whole numbers from 1x to 100x, inclusive, which should be sufficient for most applications.

However, if an experiment requires an EM Gain in excess of 100x, the [>100] button must first be selected in order to expand the slider bar's range to a maximum gain of 1000x.

NOTE:

Gain values greater than 100 may be manually entered into the EM Gain field using the keyboard without first selecting the **>100** button.

Once an EM Gain value in excess of 100 has been entered, an Experiment Warning ⚠ is raised by LightField. See Figure 14-7.

Figure 14-7: Typical EM Gain Configuration Display for EM Gain > 100
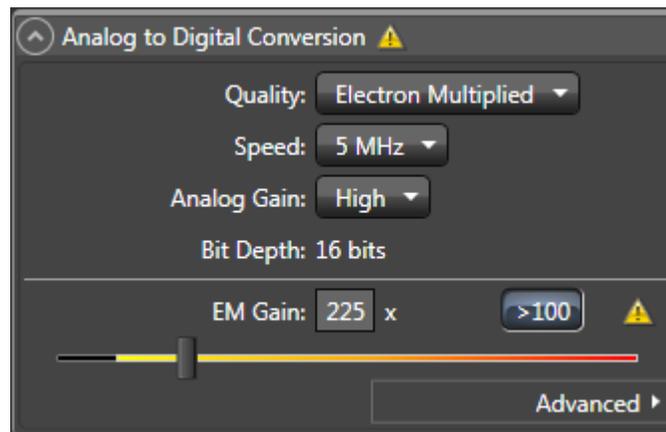
4411-0137_0124

NOTE:

When switching operation between Optimal and Manual modes, any configuration settings or adjustments made within Manual mode will be retained.

14.2   Kinetics

Kinetics is a specialized imaging mode in which a small region of a CCD's sensor area (typically referred to as a **window**) is exposed to incoming light while the balance of the sensor area is temporarily masked to prevent exposure. This masked area is then used to temporarily store previously captured images/data before they are moved to horizontal shift registers/memory.

Images are able to be captured with µs resolution by shifting each exposure under the masked region before they are transferred to memory. Since there is no overhead of readout time between each exposure, faster time resolution is achieved. At the end of a series of Exposure-Shift cycles, the entire frame is transferred to host memory at a slower transfer rate which does not negatively affect the time resolution.

14.2.1   Masking

NOTE:

The size of the window/mask is adjustable depending upon the requirements of the specific application. Once the size of the window has been determined, its height, in number of rows to be exposed, is specified with the **Kinetics Window Height** field. See Figure 14-8.

Figure 14-8: Configuring Readout Mode
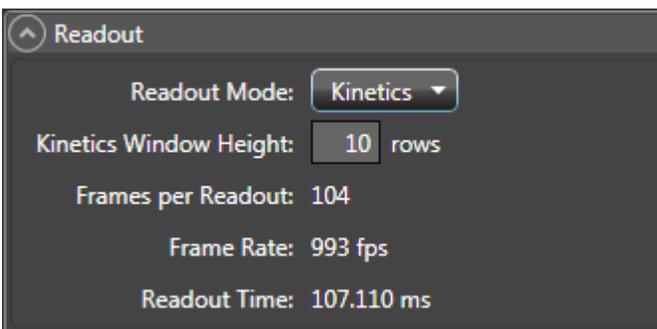
4411-0137_0125

In kinetics mode, an additional section of the CCD sensor area must be optically masked in order to minimize the cross-talk between subframes. Typically, in imaging applications, this is accomplished by placing a "knife edge" or an optical mask in the collimated beam path. Whereas, in spectroscopy, this is best achieved by limiting the height of the entrance slit of the spectrograph. In most of the applications, the ability to mask as few rows as possible sets the ultimate limit on the temporal resolution.

For best results, it is recommended that the size (in rows) of the masked area be a whole multiple of the size (in rows) of the Sensor Window. By sizing the mask to be an integer sub-multiple of the window (or as close to a whole number as possible,) the number of "empty" rows is minimized, thus maximizing the amount of valid data that have been collected.

For example, when using a 16 x 16 full frame CCD matrix, possible mask and window sizes, based on their size ratios, are shown in Table 14-1.

Table 14-1: Mask/Window Sizes for 16 x 16 CCD, Full Frame

Mask Size (Rows)	Window Size (Rows)	Mask:Window Ratio
15	1	15
14	2	7
12	4	3
8	8	1

Of course, some of these combinations are more useful than others. For most applications, specifying a 1 pixel tall window will not provide much useful data. On the other hand, specifying a 1:1 ratio may not take full advantage of the timing resolution to be gained by implementing Kinetics mode. So there are trade offs that need to be carefully assessed when designing an experiment using Kinetics mode.

Figure 14-9 shows typical Full-Frame and Frame Transfer CCDs with and without Kinetics masking. In both cases, all but four rows of the normal sensor areas have been masked for Kinetics mode.

> **NOTE:**
> The exposure area is the section of the EMCCD that is <u>farthest</u> from the serial register.

Figure 14-9: Typical Full-Frame and Frame Transfer CCDs, Kinetics Masking

Typical Full-Frame CCD   Typical Frame Transfer CCD

4411-0137_0126
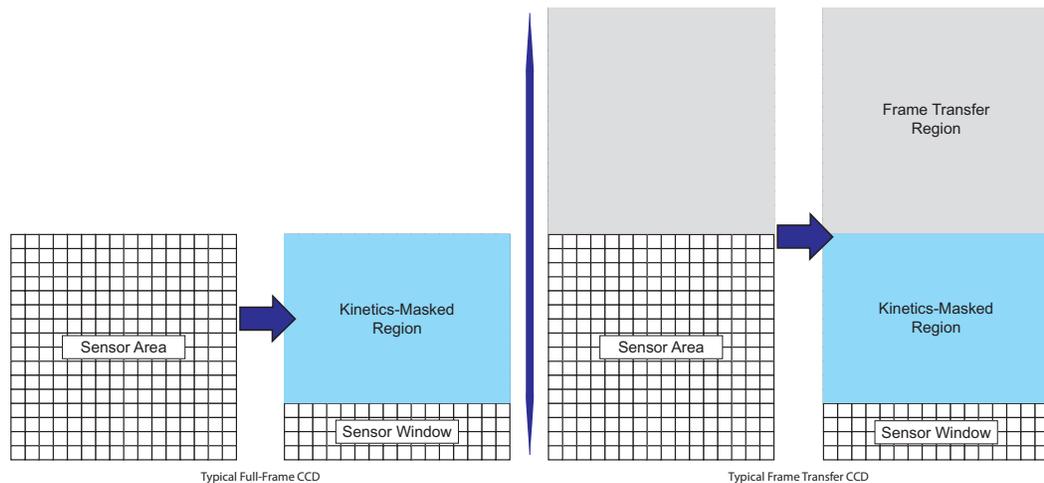
14.2.2 Trigger Sources

The trigger source for the Exposure-Shift cycle can be either internally generated by the camera and controlled by LightField, or supplied from an external source via the **Trigger In** connector on the rear of the PI-MAX4: EM. For example, when each exposure cycle must be synchronized with an external light source (e.g., a laser,) external triggering is used.

14.2.3 Image/Frame Acquisition

As with standard operation, the PI-MAX4: EM family of cameras supports two trigger modes for Kinetics:

- In **Readout Per Trigger** mode, the camera requires only one trigger to initiate an entire series of Exposure-Shift cycles. In this mode, the camera uses the exposure time that has been programmed into the software for other triggers.
- In **Shift Per Trigger** mode, each Exposure-Shift cycle is independently triggered by a single pulse.

> **NOTE:**
>
> Although gating does not result in the accumulation of light through the window, ambient light surrounding the experiment should always be minimized when using **Shift Per Trigger** mode.

Figure 14-10 illustrates and compares the timing diagrams for these Exposure-Shift modes.

Figure 14-10:Timing Diagrams: Kinetics Exposure-Shift

4411-0137_0127
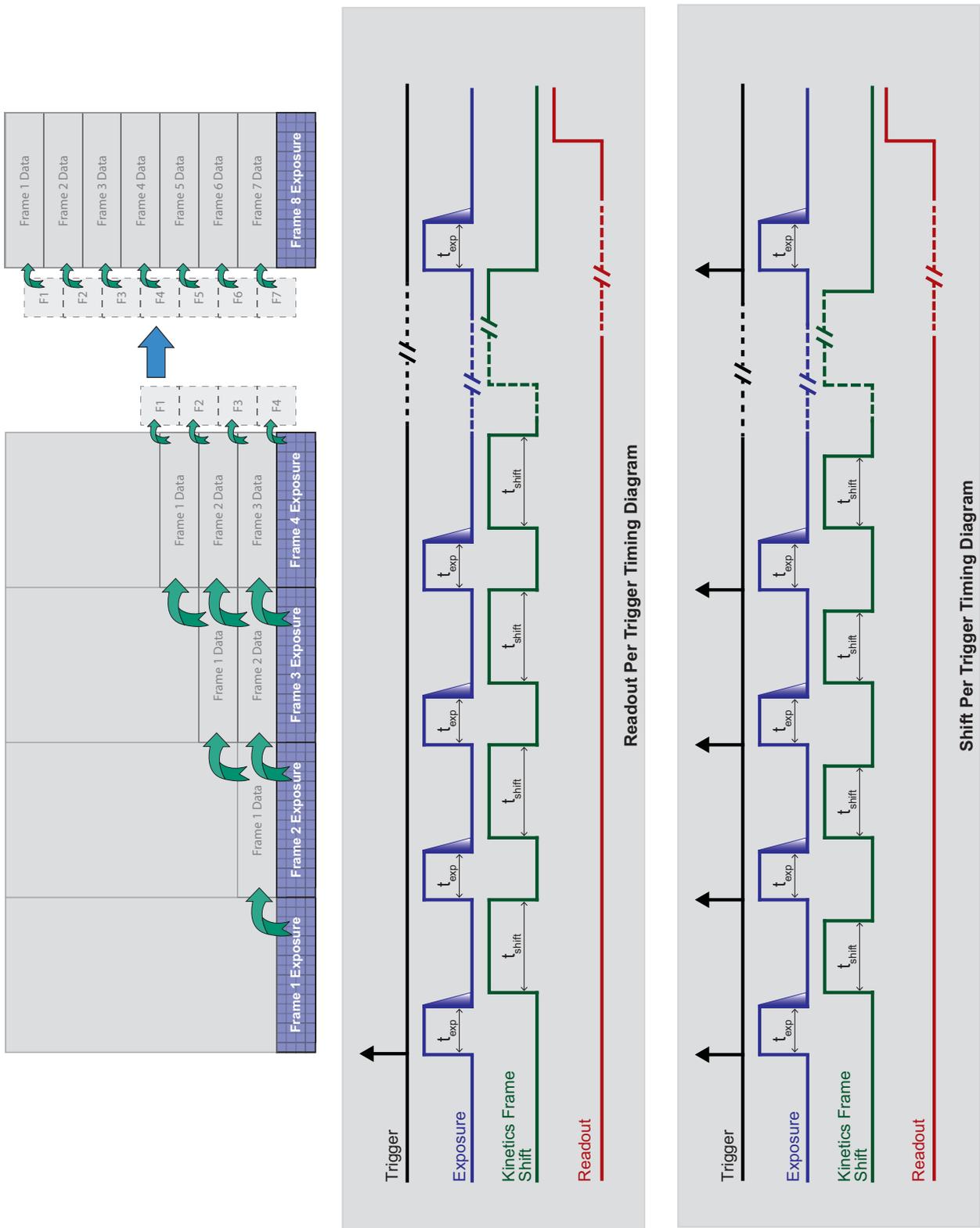
14.2.4 Data Readout

At the end of each programmed Exposure-Shift cycle, the data stored on the CCD are transferred to computer memory.

14.2.5 Binning

As with standard data readout, Binning may be implemented to reduce readout times.

> **NOTE:**
>
> Refer to Section 5.8.3, Binned Readout (Hardware Binning), on page 76 for complete information about binning readout data.

Figure 14-11 illustrates a block diagram and the timing diagram for data readout for a 4 row Kinetics frame with no binning.

Figure 14-12 illustrates a block diagram and the timing diagram for data readout for a 4 row Kinetics frame using 2 x 1 binning.

Figure 14-11:Timing Diagram: Kinetics Readout and Data Storage, No Binning, 4 Row Kinetics Frame

4411-0137_0128
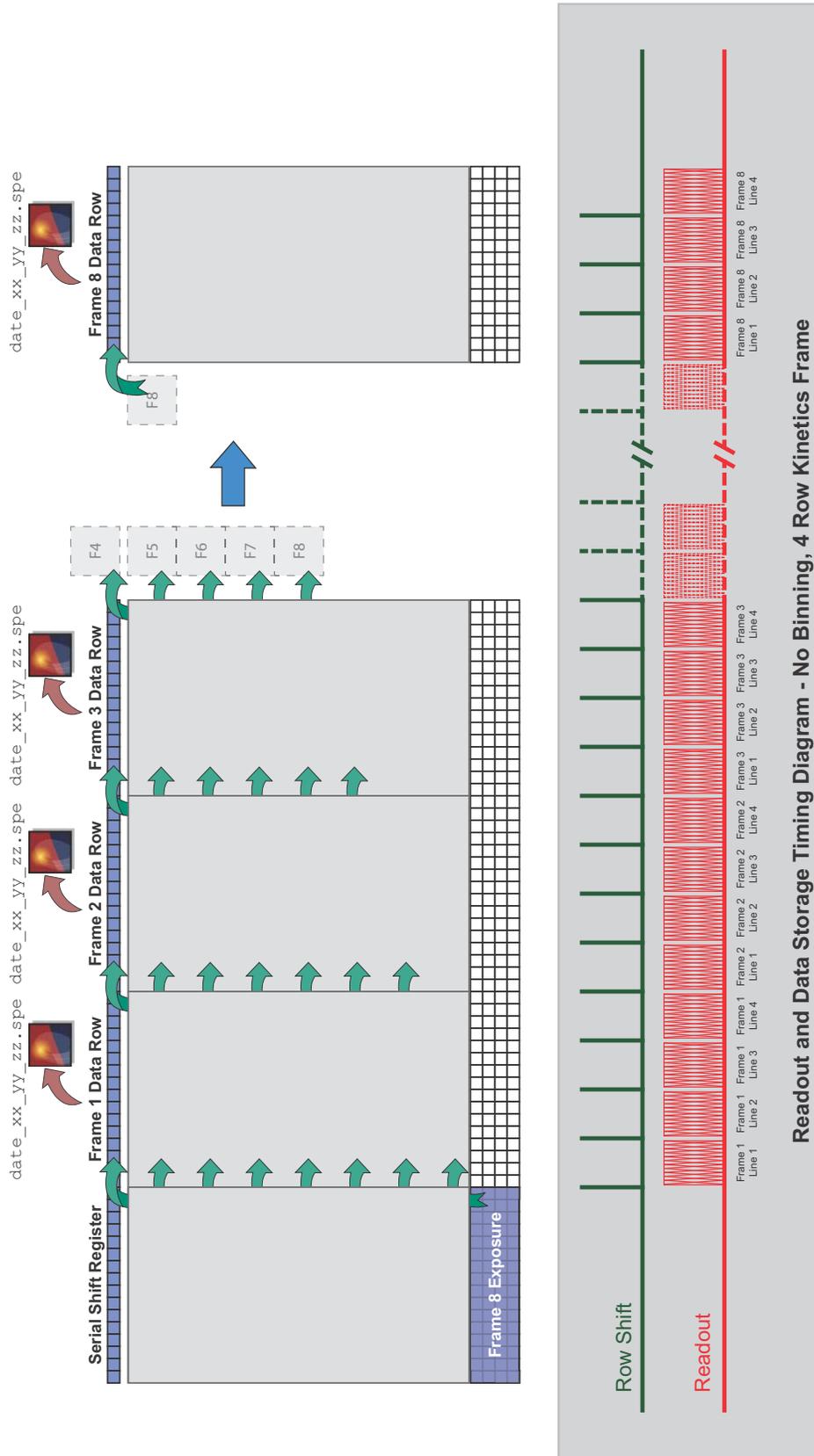
Figure 14-12:Timing Diagram: Kinetics Readout and Data Storage, 2 x 1 Binning, 4 Row Kinetics Frame

4411-0137_0129
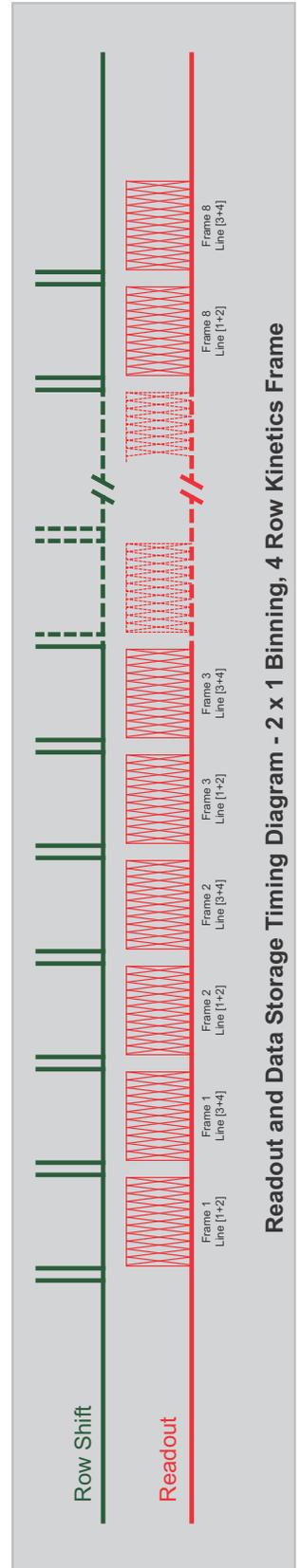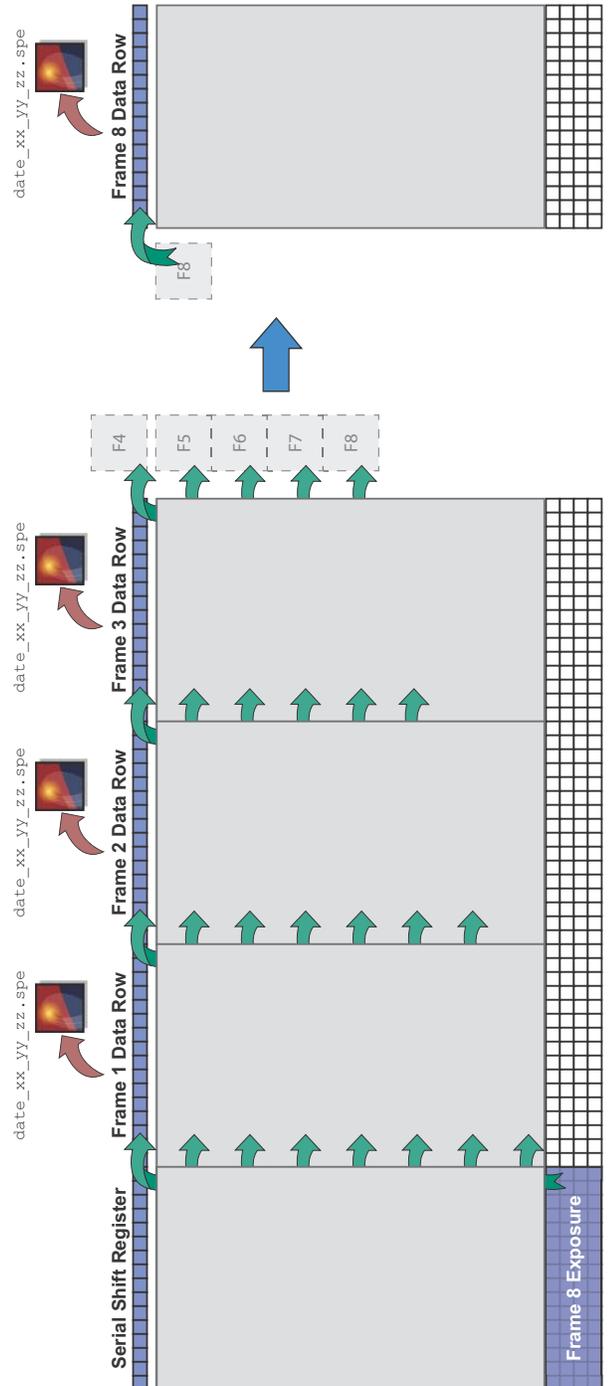
14.2.5.1 File Storage Conventions

LightField saves data for each exposure/frame as an individual file once it has been read/output from the shift register.

See Figure 14-13

Figure 14-13:File Storage Convention

Frame 1 Image	date_aa_bb_01.spe
Frame 2 Image	date_aa_bb_02.spe
Frame 3 Image	date_aa_bb_03.spe
Frame 4 Image	date_aa_bb_04.spe
Frame 5 Image	date_aa_bb_05.spe
Frame 6 Image	date_aa_bb_06.spe
Frame 7 Image	date_aa_bb_07.spe
Frame 8 Image	date_aa_bb_08.spe
Frame 9 Image	date_aa_bb_09.spe
Frame 10 Image	date_aa_bb_10.spe
Frame 11 Image	date_aa_bb_11.spe
Frame 12 Image	date_aa_bb_12.spe
Frame 13 Image	date_aa_bb_13.spe
Frame 14 Image	date_aa_bb_14.spe
Frame 15 Image	date_aa_bb_15.spe
Frame 16 Image	date_aa_bb_16.spe

4411-0137_0130

14.2.6 Configuring Kinetics

Perform the following procedure to configure a PI-MAX4: EM camera for Kinetics mode:

1. Click on the **Readout** expander and select **Kinetics** within the Readout Mode field.

2. Specify the desired **Kinetics Window Height** in number of rows.

> **NOTE:**
>
> The number of **Frames per Readout** is automatically calculated and displayed in the **Readout** expander.

See Figure 14-14.

Figure 14-14:Configuring Readout Mode
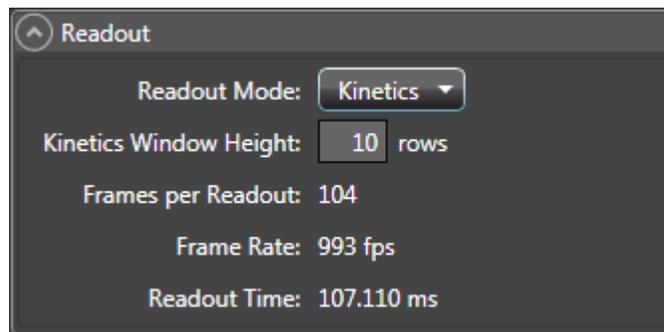
4411-0137_0125

> **NOTE:**
>
> When the **Kinetics Window Height** value is changed, the **Frames per Readout** value is recalculated. Consequently, the value specified in **Common Acquisition Settings —> Number of Frames** must be manually updated to reflect this new **Frames per Readout** value.

> **NOTE:**
>
> An Experiment Warning ⚠ is raised indicating a mismatch in configuration parameters.

3. Click on the **Trigger** expander and select the desired **Trigger Response**:

   - **Readout Per Trigg**;
   - **Shift Per Trigger**.

   See Figure 14-15.

Figure 14-15:Configuring Trigger Response
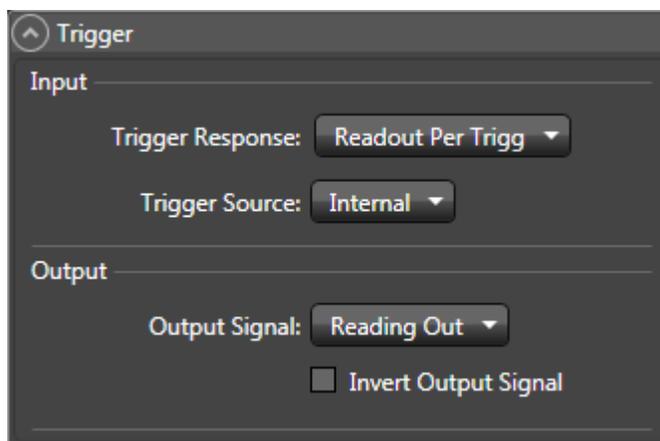
4411-0137_0131

14.2.7 Cleaning the CCD

Since kinetics is most often used in asynchronous, single-shot experiments, it is important that CCD be cleared of accumulating background or dark charge while it is waiting for an external trigger. To take care of this, PI-MAX4: EM automatically cleans the CCD "one row at a time" before the arrival of the first trigger. This keeps the charge buildup on the CCD to a minimum at the same time minimizing the timing jitter (determined by vertical shift time of a single row.) If desired, the number of cleans can be set to zero for the lowest jitter performance. However, dark current build-up may be significant depending upon the time between experiments.

14.2.8 Configuring a Kinetics Experiment

This procedure assumes:

- The system has already been setup per instructions in previous chapters.
- Previous sections of this chapter have been read and are understood.
- Familiarity with the application software.
- The system is being operated in imaging mode.
- The target is a sharp image, text, or drawing that can be used to verify that the camera is "seeing" and can be used to maximize focus.
- A portion of the CCD is being illuminated as illustrated in Figure 14-9.
- LightField is the application software being used.

Figure 14-16 illustrates a high-level block diagram of the equipment setup for a typical Kinetics experiment.

Figure 14-16: Block Diagram: Typical Kinetics Experiment

4411-0137_0132
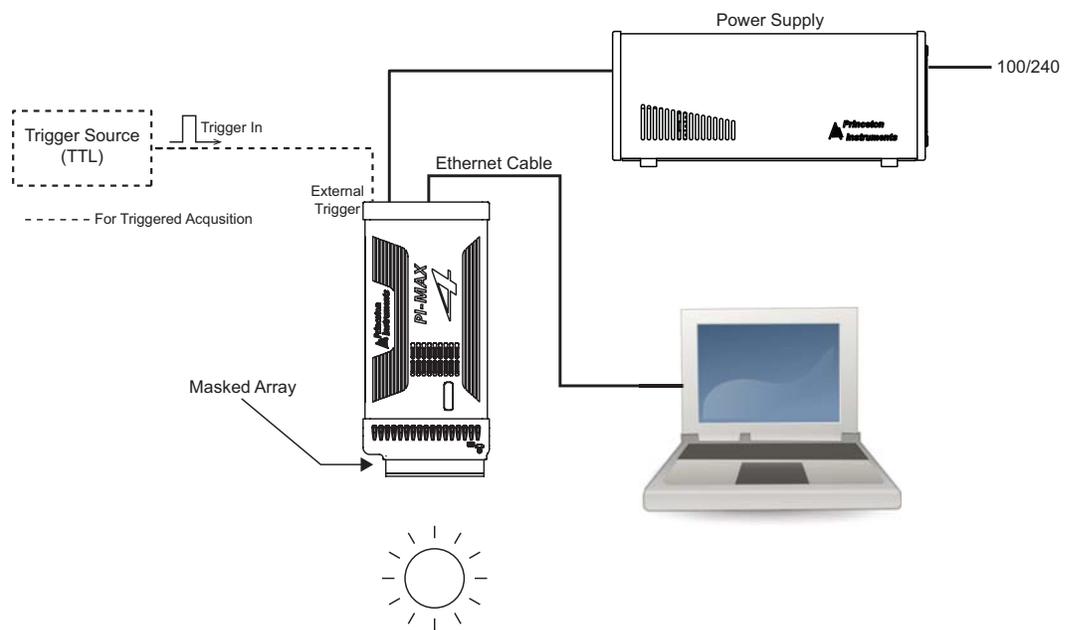
14.2.8.1 *Configuring the Software Parameters:*

> 🔍 **NOTE:** ——————————————————————
>
> The following procedure is based on LightField. When using
> different application software, modifications to this procedure
> may be required. Basic familiarity with the LightField software
> is assumed. If this is not the case, review the software manual
> or have it available while performing this procedure.

Configure the software parameters as follows:

- **Readout** expander
  - **Readout Mode**: Available modes are read from the camera. Select **Kinetics**.
  - **Kinetics Window Height**: Enter the desired number of exposed rows.
  - **Frames per Readout**: This value is automatically calculated based on the specified window height.
- **Common Acquisition Settings** expander
  - **Number of Frames**: Enter the **Frames per Readout** value calculated by the system.
  - **Exposures per Frame**: 1
- **Region of Interest** expander: Use the functions on this expander to define the region of interest (ROI.)
  - Clicking on **Full Sensor** selects the full window (without binning)
- **Sensor** expander
  - **Temperature Setpoint**: The default temperature setting is read from the camera. When the array temperature reaches the set temperature, that status will be reported as **Locked** in the **Sensor** expander and in the Status bar.
- **Trigger** expander
  - **Trigger Response**
    Valid values are:
    - **Readout Per Trigger**
    - **Shift Per Trigger**
  - **Trigger Source**
    Valid values are:
    - **Internal**
    - **External**

> 📖 **REFERENCES:** ——————————————————————
>
> Refer to the LightField User's Manual, document number
> 4411-0125, for information about configuring external trigger
> sources.

14.3   Photon Detection

Photon Detection is a method of estimating the number of photons collected by an emICCD under extremely low-light conditions. By comparing the intensity of the incoming light with a predefined minimum intensity level (measured in counts,) an estimated photon count can be derived.

The PI-MAX4: EM family of cameras supports two Photon Detection modes:

- Thresholding
- Clipping

In both of these modes, when the intensity of the incoming light falls below the minimum intensity level (in counts,) LightField interprets/records this as there having been zero incoming photons detected.

However, when the intensity of the incoming light meets or exceeds the minimum intensity level (in counts,) LightField interprets this differently depending upon which Photon Detection Mode has been selected:

- **Thresholding**
  With Thresholding, when the incoming intensity meets or exceeds the defined intensity threshold (in counts,) LightField interprets/records the incoming intensity as being exactly one photon.

  The primary advantage of Thresholding is that it provides improved Signal-to-Noise Ratios (SNR) under extremely low-light conditions.

- **Clipping**
  With Clipping, when the incoming intensity meets or exceeds the defined intensity threshold (in counts,) LightField records the incoming intensity level precisely as the measured/detected intensity level.

  The primary advantage of Clipping is that there is no information loss when intensity levels exceed the minimum threshold value.

14.3.1 Configuring Photon Detection

Perform the following procedure to configure Photon Detection:

1. If necessary, expand the **Common Acquisition Settings** expander. See Figure 14-17.

Figure 14-17:Typical Common Acquisition Settings Expander
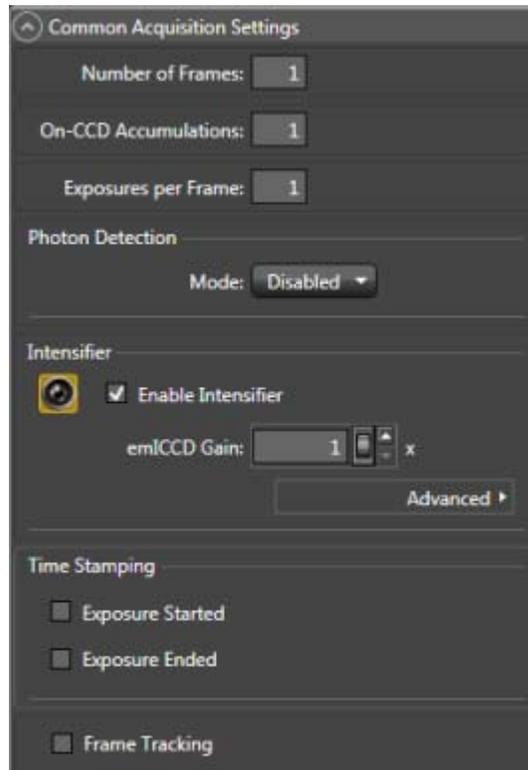
4411-0137_0133

2. Within the **Photon Detection** section, select the desired **Mode**.

Supported modes are:
- Disabled [default];
- Thresholding;
- Clipping;

3. When either Thresholding or Clipping has been selected, specify the **Threshold**, in counts, by typing in the desired level. Figure 14-18 shows the **Threshold** field for both Thresholding and Clipping modes.

Figure 14-18:Typical Thresholding and Clipping Configuration Parameters
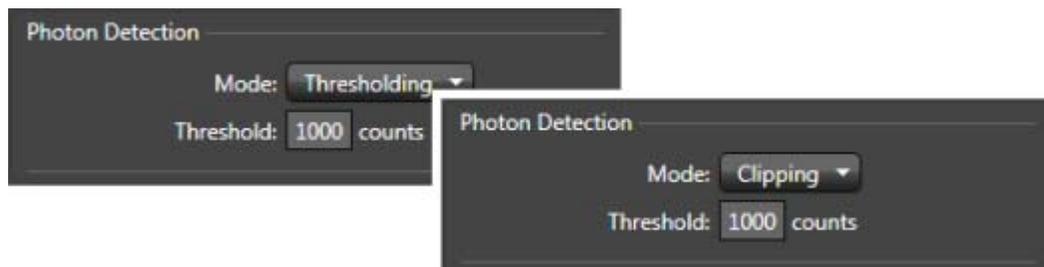
4411-0137_0134

14.4 High Speed Camera Add-in

The High Speed Camera add-in automatically modifies experiment settings to maximize the number of frames that can be acquired per second.

NOTE:

The High Speed Camera add-in is available only when a PI-MAX4: 512 EM or PI-MAX4: 1024EM camera is connected.

Figure 14-19 shows a typical **High Speed Camera** expander.

Figure 14-19:Typical High Speed Camera Expander

4411-0137_0135
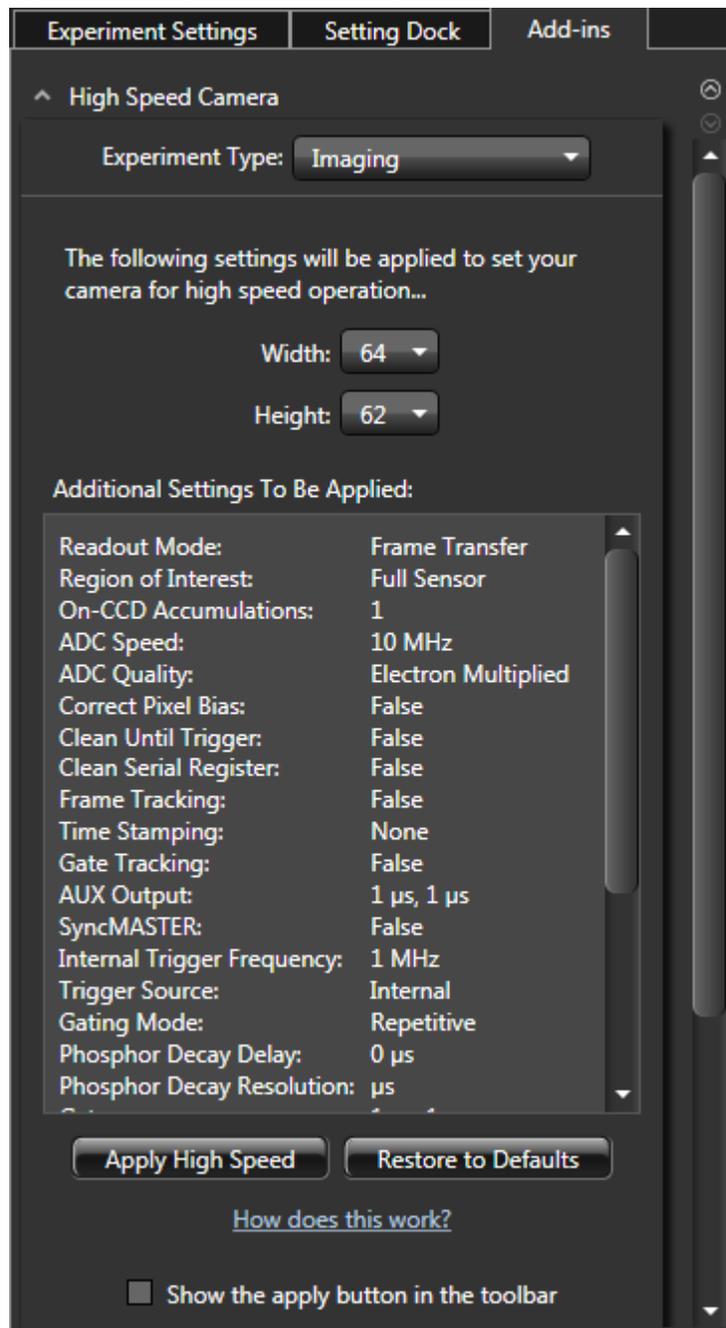
14.4.1 Configuring the High Speed Camera

Perform the following procedure to configure a PI-MAX4: 512 EM/1024 EM camera for high speed operation:

1. Click on the **Add-ins** tab and open the **High Speed Camera** expander.

    - When **Experiment Type** is selected to be **Spectroscopy**, specify the number of rows to be binned. See Figure 14-20.

Figure 14-20:Typical High Speed Camera Spectroscopy Settings
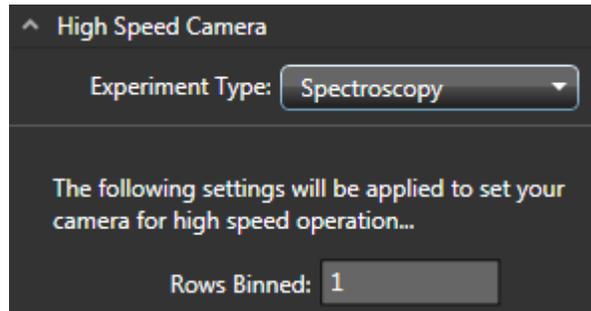
4411-0137_0136

    - When **Experiment Type** is selected to be **Imaging**, select the desired width and height values from the respective pull-down menu of available options to achieve the highest possible speed. Note that additional settings may be modified when the width and/or height are changed. See Figure 14-21.

Figure 14-21:Typical High Speed Camera Imaging Settings
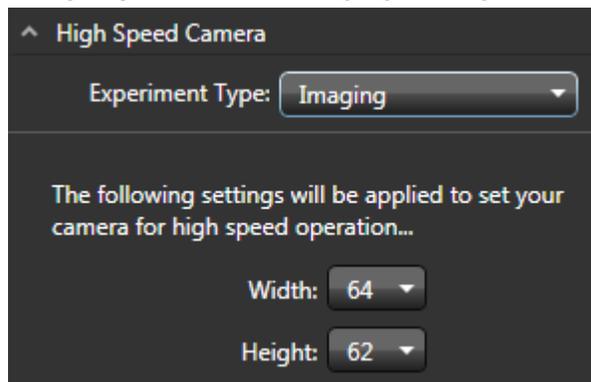
4411-0137_0137

2. Click on the **Apply High Speed** button to replace the current experiment settings with the high speed settings.

    Note that both **Previous** and **Current** frame rate information are reported near the bottom of the **Add-in** tab, similar to that shown in Figure 14-22.

Figure 14-22:Typical Previous and Current Frame Rate Information
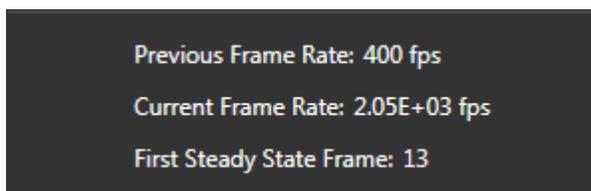
4411-0137_0138

NOTE: —————————————————

If the **Restore to Defaults** button is clicked, all experiment settings revert to the camera's default values.

3. Return to the **Experiment Settings** panel and, if necessary, open the **Common Acquisition Settings** expander. From here, the following features/options may be enabled/disabled:

- **Time Stamping**
    - — Exposure Started
    - — Exposure Ended
- **Frame Tracking**

See Figure 14-23.

Figure 14-23:Typical Configuration Options: Time Stamping, Frame Tracking
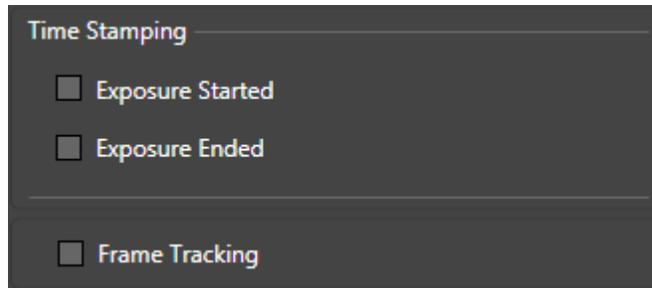
4411-0137_0139

4. Specify the **Number of Frames** to be captured (e.g., 50.)

5. Click on the **Acquire** button to acquire the frame set.

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Chapter 15: Tips and Tricks

In prior chapters, the objective was to show how to take an image or spectrum with a minimal operating configuration and following a simple procedure. In this chapter, factors that affect more complex measurements are discussed.

15.1   Overexposure Protection

WARNING!

Image intensified cameras such as the PI-MAX4 can be *destroyed* if exposed to excessive light levels. Princeton Instruments cannot take responsibility for damage due to misuse.

Intensified cameras must not be continuously exposed to high-level radiation (≥ 10-4 foot candles.) When the illumination level is not quantitatively known, toggle the **I.I.T.** switch (located on the back of the PI-MAX4) to the OFF position while you are adjusting the incoming light level. After making adjustments, toggle the switch to the **ON** position. If the alarm sounds repetitively, toggle the switch back to **OFF** and readjust the lighting conditions.

If the experimental conditions dictate that only a small portion of the photocathode is illuminated over relatively long periods of time, change the illuminated region of the photocathode periodically to avoid long term localized photocathode or MCP damage.

If you can do so, it is a good idea to avoid intense light on the intensifier even when it is off. High light levels increase EBI, often for hours, even when the intensifier is off. Image burn-in can occur with some photocathode types.

NOTE:

The audible alarm and protection circuits are not fail-safe protection, particularly when working with high intensity sources such as lasers. For additional information, refer to Section 7.2.2, Alarms, on page 121.

15.2   Signal Delay

For the camera to see a transient signal, it is essential that it be gated on when the signal arrives at the camera. If this requirement is not given careful consideration, it is possible to set up an experiment in which the signal will come and go *before* the camera is gated on. If this happens, no proper data can be taken. Depending on the nature of the experiment and the specific equipment involved, a number of different factors may need to be considered to be assured that the camera gates at the right time.

15.2.1   Time Budgets

A time budget is a listing of all the delays in the system that affect coincidence of the signal and gate at the camera. Given a system that, in addition to the PI-MAX4 and an internal timing generator, contains a low-jitter pulsed laser triggered from an external timer and an external trigger source that is also triggering the pulse generator, a time budget for this system might be developed as follows.

PI-MAX4 Internal Timing Generator Time Budge Calculation

- **Signal Delay**
  — Cable Delay from External Timer to Laser: 10 ns (6 ft cable is assumed)
  — Delay (at laser); Trigger to Laser Pulse: 10 ns
  — Delay; Laser Pulse to Sample: 10 ns
  — Delay; Fluorescence Signal to Detector: 5 ns

  Total Signal Delay: 35 ns

- **Gate On Delay**
  — Cable Delay from External Timer to PI-MAX4: 15 ns (10 ft cable is assumed)
  — PI-MAX4 Insertion Delay; Trigger to Start of Gate Open Pulse: 25 ns

  Total Gate On Delay: 40 ns

In this example, although the Signal Delay and the Gate On Delay are close, if the signal is a pulse lasting only a few nanoseconds, it will have come and gone before the Gate opens, and no valid experimental data could be taken. Obviously, this sample time budget is unlikely to match any actual system and the values for both the Signal Delay and the Gate On Delay could be very different from those indicated here. Nevertheless, it illustrates the importance of making a record of the delays that will be encountered in any system to determine their possible impact on experimental results.

15.2.2 Measuring Coincidence

In addition to preparing a Time Budget, it is advantageous if you can directly measure the timing of the critical signals. A fast oscilloscope can be used for this purpose. Without an oscilloscope to monitor the signals, it will be difficult to determine the timing with sufficient accuracy.

> ☞ **TIP:** ───────────────────────
>
> If a set of matching probes is available, use them. Major brand oscilloscope probes of the same model are usually matched to better than 1 ns.
>
> When using coaxial cables, measure the delay of each cable and use that information in the calculations.

The PI-MAX4 **Monitor** BNC connector provides a pulse coincident with respect to the actual intensifier photocathode gating by ±5 ns. Note that this output is not designed for good fidelity but rather for accurate timing. The amplitude is typically more than a volt and we suggest that you monitor the pulse with a high impedance probe (you can also use 50 Ω coaxial cable to a 50 Ω oscilloscope and you will get a lower amplitude pulse.)

The signal timing will probably be more difficult to measure. Typically, you might divert a small portion of the laser beam using a pellicle mirror located near the sample position. By directing the beam to a PIN diode module, you could obtain an electrical signal that could be monitored with the oscilloscope to accurately indicate the arrival of the laser beam at the sample position. Note that the indicated time would have to be corrected for the insertion delay of the path from the pellicle mirror to the oscilloscope, including the insertion time of the PIN diode, which might be on the order of the 10 ns. This correction would have to be compared with the delays that would normally exist between the sample position and the camera to determine the actual time the signal would arrive at the camera. Also, the oscilloscope will have its own insertion delay, perhaps 20 ns, and an uncertainty of nominally 1% of the time base.

Another consideration is how to trigger the oscilloscope. If there is a common trigger source for the sample position signal and for the gating, that trigger could also be used to trigger the oscilloscope, allowing both signals to be observed simultaneously. Another possibility is to trigger the oscilloscope from the PIN diode signal to observe the Monitor signal, or to trigger the oscilloscope from the Monitor signal to observe the PIN diode signal. The signal that occurs first would have to be used as the oscilloscope trigger. **This is not necessarily always the case. Digital oscilloscopes can display signals that occur before the trigger.**

15.2.3 Adjusting the Signal Delay

The PI-MAX4 internal timing generator gives the user wide latitude with respect to adjusting the delay between the time the timing generator is triggered and the time the Gate On and Off edges are generated. This being the case, as long as the light signal applied to the camera occurs **after** the minimum delay time of the timing generator (~25 ns,) there will be no problem establishing the necessary coincidence.

On the other hand, if the light signal applied to the camera occurs **before** the minimum delay time of the timing generator, then no amount of adjusting the delay at the timing generator can rectify the problem. The light signal itself will have to be delayed.

If a common source is triggering both the timing generator and the laser, a very convenient solution is to insert an electrical delay by placing a long cable between the trigger source and the laser. This is generally preferable to establishing the necessary delay optically via mirrors or fiber optic cable.

Alternatively, pass the laser output through a length of optical fiber cable. By using different lengths of fiber, almost any desired signal delay can be achieved. Yet another solution would be to set up two separated parallel mirrors with a small angle between them. Typically, it will be easily possible to bounce the laser beam back and forth between the mirrors half a dozen times to obtain the necessary delay. In any case, once the light signal is arriving at the camera **after** the minimum gate time, the timing generator delay adjustments can be used to bring them into coincidence. Keep in mind that using optical cable or mirrors to delay the signal will carry some intensity penalty, which might have an adverse affect on measurement results in some experiments.

15.2.4 Optimizing the Gate Width and Delay

When the basic delay questions have been answered, the next consideration is optimization of the Gate Width and Delay. The goal is to have the gate just bracket the signal event. One effective approach is to:

1. Begin with minimum delay and a gate width far wider than the optical signal pulse to be measured.

2. While observing the data signal at the computer monitor, gradually increase the delay until the event vanishes. This will mark the point at which the gate is opening just *after* the signal, causing the signal to be lost.

3. Reduce the delay until the signal reappears.

4. Then begin reducing the gate width (not the delay.) As the gate is narrowed, the amount of Equivalent Background Illumination (EBI) generated will decrease so the signal-to-noise ratio should improve. When the point is reached where the gate becomes narrower than the signal being measured, the observed signal data will degrade. You may have to adjust the delay to keep the signal in view.

5. From there increase the width slightly for maximum signal and optimum signal-to-noise.

15.3   Lasers

Pulsed lasers are used in many experiments where a gated intensified camera might be used to recover the signal. For example, in combustion measurements, a laser pulse might be applied to a flame and the resulting fluorescence studied as the signal to be analyzed. Because this short-term signal is much weaker than the integrated light emitted by the flame, an intensified gated camera should be used to do the measurement.

Because available lasers differ so widely with respect to their characteristics and features, there is no way to discuss specifically how to incorporate your particular laser into a measurement system. It is necessary that users be familiar with the features, operation, and limitations of their equipment. Nevertheless, the following observations might prove helpful.

15.3.1 Free Running Lasers

These lasers behave essentially as oscillators. They typically exhibit little jitter from pulse to pulse and are very easy to synchronize with the experiment. If the laser has a Pre-trigger Output, it can be used to trigger the timing generator. If the interval between the Pre-trigger and the laser output is long enough, the timing generator delay can then be adjusted to catch the laser pulse following each pre-trigger. If the interval between the Pre-trigger and the laser output isn't long enough to accommodate all the insertion delays, the timing generator delay can be adjusted to catch the **next** laser pulse. **As long as the laser's jitter relative to the period is small**, this is a perfectly valid way to operate. If the laser does not have a Pre-trigger Output, one option is to use a pellicle mirror and a PIN diode to obtain the timing generator trigger. Again, the timing generator delay could be adjusted to catch the **next** laser pulse to achieve the necessary synchronization between the optical signal and the photocathode gate at the camera, although this would cause at least every other laser pulse to be lost.

15.3.2 Triggered Lasers

Timing Generator as Trigger Source

Using the PI-MAX4's **SyncMASTER1** signal to trigger the laser eliminates the propagation delay for the External Trigger (25 ns) and all timing is relative to T_0. You will still need to consider the delays from the cable to the laser (1.5 ns/ft,) internal delay from trigger to firing (laser dependent, 50 ns for example,) and the PI-MAX4's internal minimum allowable gate delay (~25 ns.)

External Source Triggers Both Timing Generator and Laser

This is the more complex case because it contains many sources of delay that would have to be considered. A carefully prepared Time Budget could prove invaluable in determining what steps need to be taken to bring the gate and signal into coincidence at the camera. In addition, actually measuring delays with a fast oscilloscope as previously described could be very helpful. If the laser provides a **Pre-Trigger** output that can be used to trigger the Timing Generator, it may not be necessary to use mirrors or fiber-optic cable to delay the laser pulse. If there is no **Pre-Trigger**, then taking steps to delay the arrival of the laser pulse at the sample would likely be necessary. The easiest solution would be to insert electrical delay between the external trigger source and the laser.

15.3.3   Jitter

Jitter, uncertainty in the timing of the laser output, is a critical laser performance parameter in gated experiments. If the jitter is significant relative to the duration of the signal pulse, the gate width will have to be wide enough to accommodate it, and the temporal discrimination against unwanted signal will be reduced. Some types of high power laser pulse have considerable jitter, even using a pre-trigger. Where this is the case, there is no choice but to trigger from the actual laser pulse. One way of doing that is to use a pellicle mirror and PIN diode as previously described and then to delay the light (usually by multiple reflections between mirrors or in an optical fiber) until the gate opens.

15.4   Inhibiting the Pulser During Readout

In Gate mode operation, if gating pulses are applied to the camera during a readout, it will cause undesirable artifacts in the data. In experiments where the time between cycles is longer than the readout time, there is no possibility of this happening and it is not a matter of concern. If the experiment is such that it is possible for a new gate to be applied before the readout of the previously gathered data set is complete, preventive action will be required. With a PI-MAX4, the timing generator is inhibited internally.

15.5   Lens Performance

Imaging applications require that a lens be mounted to the camera. Because the lens characteristics affect system performance, it may be helpful to review some basic lens concepts. Basically, light from an object enters the front of the lens and is focused to a sharp image on the photocathode of the intensifier. The ability of the lens to do this well depends on a number of factors, each of which is described the following sections.

15.5.1   Throughput

The throughput of a lens is determined by its aperture, which can ordinarily be set to a number of different values or f/ stops. The higher the number after the slash, the smaller the aperture and the lower the throughput. Depth of field considerations make the focus adjustment most sensitive at maximum aperture (i.e., the smallest f/ stop.)

15.5.2   Depth of Field

Depth of field is a measure of how the sharpness of a lens varies with respect to the distance of an object from the lens. For any given aperture, there is a depth of field, usually marked on the barrel of the lens. Objects within the zone will be sharply imaged. Objects closer or further than the depth of field will not be as sharp. The further an object is from the point of sharpest focus, the less sharp its image on the CCD will be. **The point of maximum sharpness is located 1/3 of the way into the depth of field zone.** For example, if the indicated depth of field for the selected aperture extended from 3 ft to 6 ft, the point of maximum sharpness will be at 4 ft.

For good focusing sensitivity, the depth of field should be small (large aperture.) If the aperture is small, the depth of field will be deep, making it difficult to establish the point of sharpest focus. For example, with a 50 mm lens, at f/4 the depth of field will extend from 8 ft to infinity. By focusing at full aperture, the depth of field will be as shallow as possible. As a result, the effects of even very small focusing adjustments will be readily observed, allowing the focus to be set with precision. Once the optimum focus setting has been achieved, the aperture can be reduced to the point of maximum sharpness. In some experiments, you may wish to adjust the aperture for optimum signal level. However, the experiment setup parameters established with the applications software can also be used to adjust the signal level, allowing the lens aperture and focus to be optimized.

15.6   Baseline Signal

With the camera completely blocked, the CCD will collect a dark charge pattern, dependent on the exposure time, camera temperature, and intensifier gain setting. The longer the exposure time and the warmer the camera the larger and less uniform this background will appear.

After temperature lock has been established, wait about 5 minutes for the camera temperature to completely stabilize. Then try taking a few dark charge readings with the camera operated with the I.I.T. switch set to OFF.

> **NOTE:**
>
> Do not be concerned about either the baseline level of this background or its shape, unless it is very high, i.e., > 1000 counts (or > 3000 counts at Gain = 2 for some cameras.) What you see is not noise. It is a fully subtractable readout pattern. Each CCD has its own dark charge pattern, unique to that particular device. In addition, a small offset is built in to prevent noise or pattern from going below zero. Every device has been thoroughly tested to ensure its compliance with Princeton Instruments' demanding specifications.

15.7   Temperature Lock

If the PI-MAX4Detector loses temperature lock, the internal temperature of the camera has gotten too high, such as might occur if the operating environment is particularly warm or if you are attempting to operate at a too cold temperature. If this happens, an internal thermo-protection switch will disable the cooler circuits to protect them. Although the thermo-protection switch will protect the camera, users are advised to power down and correct the operating conditions that caused the thermal-overload to occur. Note that the cooling performance of the camera can be enhanced by circulating water coolant. Refer to

Turn the controller off for fifteen or twenty minutes. Then turn it back on and set a warmer temperature from the software **Detector Temperature** dialog. Temperature lock should be re-established within a few minutes.

15.8   Intensifier Alarm

> ⚠ **CAUTION!**
>
> Contact the factory at once if sporadic or continuous unwarranted alarms occur. They may indicate intensifier damage or another situation that requires immediate attention.

To reduce the risk of camera damage, PI-MAX4 cameras are equipped with an audible alarm in the camera head, activated when the intensity of light falling on the image intensifier exceeds a preset threshold. While the alarm is sounding, the photocathode is temporarily disabled. Toggle the **I.I.T.** switch on the back of the PI-MAX4 to the **OFF** position. Cover the camera window and only switch the **I.I.T.** switch to **ON** after the illumination level has been lowered. If the alarm sounds repetitively even when the illumination level is adequately low, select **Safe Mode** in the WinX application or shut the system down and contact the factory for guidance.

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Chapter 16: Component Descriptions

PI-MAX4 is an advanced intensified CCD (ICCD) camera system used for low light and time resolved applications. It consists of an imaging (square) or spectroscopy (rectangular) format CCD coupled to Gen II (PI-MAX4 RB, SB, UV) or Filmless Gen III (PI-MAX4 HQ) intensifiers. The operation of the camera system is under complete control of WinView/32 (Imaging,) WinSpec/32 (Imaging and Spectroscopy,) or LightField software packages. In pulsed/gated experiments where the camera needs to be synchronized to a light source (e.g., a laser,) the internal timing generator is used.

16.1 Mount Adapters

The nose at the front end of a PI-MAX4 camera is designed to accept three types of mount adapters:

- C-mount;
- F-mount;
- Spectroscopy-mount.

The mount adapter specified when the system was ordered was installed on the camera at the factory, additional mount adapters may be ordered.

📖 **REFERENCES:** ───────────────────

For additional information about specific mount adapters, refer to:

- Appendix E, C- and F-Mount Information, on page 281;
- Appendix F, Spectrograph Mount Information, on page 285;
- Appendix G, Accessories, on page 293.

16.2   Switches, Connectors, and Indicators

This section provides information about the switches, connectors, and indicators found on the PI-MAX4 family of cameras.

- Figure 16-1 shows the typical PI-MAX4 Rear Panel;
- Figure 16-2 shows the PI-MAX4: 1024i-RF Rear Panel.

Figure 16-1: PI-MAX4 Rear Panel

4411-0137_0140

Figure 16-2: PI-MAX4: 1024i-RF Rear Panel

4411-0137_0116

Rear panel switches, connectors, and indicators are presented in alphabetical order.

- When a switch, connector, or indicator is unique to the PI-MAX4: 1024i-RF, its description will specify PI-MAX4: 1024i-RF.
- Similarly, when a switch, connector, or indicator is unique to the PI-MAX4:EM, its description will specify PI-MAX4:EM.

16.2.1 AUX I/O

This is a 26-pin female DB connector. The standard AUX I/O cable included with all PI-MAX4 systems, provides easy access to five (5) I/O signals which can be used to input a trigger to initiate data acquisition, monitor frame readout status, and/or control an external shutter.

The five I/O signals are:

- T0 Out;
- Pre-Trigger In;
- SyncMASTER1;
- General Purpose Input 0;
- SyncMASTER2.

Refer to Section A.6, AUX I/O Interface, on page 258 for complete information about the AUX I/O interface.

16.2.2 AUX Out

This is a standard female BNC connector.

The AUX Out signal is a DC-coupled programmable delay trigger output (T0) used to synchronize external devices with PI-MAX4. The host software sets the Delay Time for this output with respect to the internal timing generator trigger time.

The delay is programmable from 0.01 ns to 1 second.

The source impedance is approximately 100 Ω and it will provide > 1 V into 50 Ω.

16.2.3 AUX Power [PI-MAX4: 1024i-RF only]

Power input for the RF modulation section of a PI-MAX4: 1024i-RF camera.

16.2.4 Coolant Ports

Two standard ¼-inch barbed brass fittings for circulating coolant are located on the back panel. Either port may be used as the inlet.

⚠ **CAUTION!** ───────────────────

The coolant **cannot** be chilled.

Use Princeton Instruments' CoolCUBE$_{II}$ coolant circulator.

📖 **REFERENCES:** ───────────────

For additional information, refer to:
- Section 3.7, Connect the Circulator [Liquid-Cooled Cameras Only], on page 42;
- Section 5.5, Temperature Control, on page 66.

🔍 **NOTE:** ───────────────────────

Although circulating water will extend the camera's cooling capabilities, it is not necessary. Most of the camera's cooling is provided by the fan.

16.2.5 Error LED

Red LED indicator to warn of excessive repetition rate. Must be off for proper operation.

> **NOTE:**
>
> With the PI-MAX4, the Error LED is also activated by MCP bracket pulsing. The MCP bracket repetition rate limit is 6.25 kHz.

16.2.6 Fan

Ventilation fan that runs continuously to remove heat generated by the thermoelectric cooler and the electronics. Air is drawn into the camera through the rear grill, picks up the heat from the electronics and the cooler, and is then exhausted through the side ventilation slots.

16.2.7 Gig-E

This is a standard female RJ45 Gigabit Ethernet connector.

16.2.8 I.I.T. PWR On/Off Switch

This switch biases the image intensifier photocathode ON or OFF.

When the I.I.T. switch is set to **ON**, the photocathode can be gated ON.

> ⚠ **CAUTION!**
>
> **Make note of the following exception:**
>
> In WinSpec, selecting **SAFE** on the **Experiment Setup —> Main** screen overrides control and will prevent the photocathode from being biased on regardless of the I.I.T. switch setting.

When the I.I.T. switch is set to **OFF**, then the photocathode cannot be turned on from software.

> ⚠ **CAUTION!**
>
> It is strongly advised that the I.I.T. switch be set to **OFF** as a fail-safe measure when the camera remains ON but will be unused for a period of time.

16.2.9 Logic Out

This is a standard female BNC connector.

0 to +3.3V$_{DC}$ programmable logic level output (TTL-compatible.) The output can be programmed via software as one of the following signals:

- ACQUIRING;
- IMAGE SHIFT;
- LOGIC 1;
- READ OUT;
- SHUTTER;
- WAIT FOR TRIGGER.

> **REFERENCES:**
>
> For detailed information about each of these signals, refer to Section 5.12, Logic Out Control, on page 84.

When the **Invert LOGIC** check box is checked, the output is at a logic low when the action is occurring.

16.2.10 Mon RF Out [PI-MAX4: 1024i-RF only]

This is a standard female BNC connector. Provides an approximate indicator of the user-defined RF applied to the photocathode.

16.2.11 Monitor

This is a standard female BNC connector. This TTL signal is used to monitor actual gate timing.

The TTL logic 1 pulse is delayed ±3 ns with respect to photocathode gating.

> **NOTE:**
>
> Cable delay, ~1.5 ns/ft, is in addition to the delay at the connector.

16.2.12 Power Connector

7-pin D specialty connector. Connects to the standard PI-MAX4 power supply. See Figure 16-1.

16.2.13 Ready Out

This is a standard female BNC connector. This normally LOW TTL signal indicates the camera status. It changes state upon the completion of cleaning cycles prior to an exposure.

16.2.14 Thermoelectric Cooler

The thermoelectric (TE) cooler is mounted to the heat removal block. With air-cooling alone, at an ambient temperature of 25°C, temperature lock at 25° will generally occur within ten to fifteen minutes. Note that the exact cooling performance is a function of the CCD array installed. Also, if the ambient temperature is particularly warm, achieving temperature lock might take longer, or may not occur at all.

16.2.15 Trigger In

This is a standard BNC connector, and serves as the main trigger input to the timing generator when external triggering is used.

When external triggering is selected in the software, the internal timing generator will be triggered by an externally-derived trigger pulse (range of ±5.5 V) applied to this input. The threshold, slope, coupling mode (i.e., AC or DC,) and input impedance (i.e., High or 50 Ω) are selectable in software.

The adjacent green **TRIGGER IN** LED flashes each time the camera is triggered (glows steadily at high repetition rates.) The actual triggering can also be readily determined by observing the signal at the **Monitor** output with a fast oscilloscope.

16.2.16 User RF Out [PI-MAX4: 1024i-RF only]

This is a standard female BNC connector. User-programmable continuous frequency output to synchronize external devices with PI-MAX4: 1024i-RF. When used, this must be connected to a standard 50 Ω RF load.

> **WARNING!**
> Always turn the power off at the power supply before connecting or disconnecting any cable that interconnects the camera and the computer or serious damage to the CCD may result. This damage is **NOT** covered by the manufacturer's warranty.

16.3   Gig-E Ethernet Card

This card must be installed in the host computer to control the PI-MAX4 camera and to receive data from the camera.

16.4   Extender Bracket Kit

Each PI-MAX4 camera is shipped with an Extender Bracket kit that, when mounted to the rear of the camera, allows the PI-MAX4 to be secured to a laboratory table using tapped mounting hole arrays with ¼-20 on 1-inch spacing, or M6 on 25 mm spacing.

16.5   CoolCUBE$_{II}$ Coolant Circulator (Option)

Liquid-cooled PI-MAX4 cameras can cool to a lower temperature (typically -35° C) than air cooling. Instead of using a fan to remove heat, these cameras incorporate a closed loop system of circulating fluid. The CoolCUBE$_{II}$ circulator unit continuously pumps the 50:50 mixture of room temperature (23ºC) water and ethylene glycol. To prevent voiding the warranty, use only the circulator and hoses shipped with your system.

REFERENCES:

For technical specifications for the CoolCUBE$_{II}$ Coolant Circulator, refer to Section A.7, CoolCUBE$_{II}$ Circulator Specifications, on page 261.

16.6   Spectrograph (Option)

The system may also include a spectrograph. If so, the camera must be properly mounted to it as described in the manual supplied with the spectrograph. If the spectrograph will be computer-controlled, a suitable interface cable will additionally be required.

REFERENCES:

For information about mounting a PI-MAX4 to a spectrograph, refer to Appendix F, Spectrograph Mount Information, on page 285.

16.7   Cables

The cables described below may be supplied with the PI-MAX4 system.

- **Ethernet Cable**
  This standard 5 meter (16.4') cable is a Cat 5e/6 Ethernet cable (6050-0621) for interconnecting the camera and the host computer. The distance between the camera and the computer can be over 50 meters. Please contact the factory for longer cables.

- **AUX I/O Cable**
  The I/O cable (6050-0660) has a female, DB26, high-density connector that connects to the **AUX I/O** connector. The five (5) BNCs at other end of the cable provide access to five I/O signals that can be used to input a trigger to initiate data acquisition, monitor frame readout status, and/or control an external shutter.

  REFERENCES:

  Refer to Section A.6, AUX I/O Interface, on page 258 for complete information.

- **Additional Cables**
  Additional cables may be required depending on specific system requirements.

16.8   Tubing

Clear PVC tubing (3', 5/32" OD, 1/32" wall McMaster-Carr 5006K42) is supplied with the PI-MAX4. This tubing is for connecting the PI-MAX4 to a dry nitrogen source for cooling the photocathode.

16.9   Application Software

The following application software may be supplied with the PI-MAX4 system:

- **WinX**
  The PI-MAX4 camera can be operated by using either WinView/32 or WinSpec/32, Princeton Instrument's 32-bit Windows® software packages designed specifically for high-end imaging and spectroscopy, respectively. The Princeton Instruments' software provides comprehensive image/spectral capture and display functions. The package also facilitates snap-ins to permit advanced operation. Using the optional built-in macro record function, you can also create and edit your own macros to automate a variety of operations.

- **PVCAM™**
  The standard software interface for cooled CCD cameras from Roper Scientific. It is a library of functions that can be used to control and acquire data from the camera when a custom application is being written. For example, in the case of Windows, PVCAM is a dynamic link library (DLL.) Also, it should be understood that PVCAM is solely for camera control and image acquisition, not for image processing. PVCAM places acquired images into a buffer, where they can then be manipulated using either custom written code or by extensions to other commercially available image processing packages.

- **Scientific Imaging ToolKit™**
  SITK™ is a collection of LabVIEW® VIs for scientific cameras and spectrographs. This third party software can be purchased from Princeton Instruments.

- **LightField®**
  The PI-MAX4 can be operated using LightField, Princeton Instrument's 64-bit Windows Vista® and Windows® 7 compatible software package. LightField combines complete control over Princeton Instruments' cameras and spectrographs with easy-to-use tools for experimental setup, data acquisition and post-processing. LightField makes data integrity priority number one via automatic saving to disk, time stamping and retention of both raw and corrected data with full experimental details saved in each file. LightField works seamlessly in multi-user facilities, remembering each user's hardware and software configurations and tailoring options and features accordingly. The optional, patent-pending IntelliCal™ package is the highest-performance wavelength calibration software available, providing up to 10X greater accuracy across the entire focal plane than competing routines.

- **PICam™**
  The standard 64-bit software interface for cooled CCD cameras from Princeton Instruments. PICam is an ANSI C library of camera control and data acquisition functions. Currently, the interface supports Windows Vista and Windows 7.

16.10 User Manuals

The following User Manuals may be included with the PI-MAX4 system:

- **PI-MAX4 System User Manual**
  This manual describes how to install and use the PI-MAX4 system components.

- **WinView/32 or WinSpec/32 User Manual**
  This manual describes how to install and use the application program. A PDF version of this manual is provided on the installation CD. Additional information is available in the program's online help.

- **LightField® User Manual**
  This manual describes how to install and use the LightField application program (for 64-bit Windows Vista® and Windows® 7 operating systems.) The manual is provided in PDF version on the installation CD and will be installed in the Princeton Instruments/LightField/Documents subdirectory. Acrobat 7.0 or higher is required. Additional information is available in the program's online help.

NOTE:

Up-to-date copies of Princeton Instruments manuals are available for download as a pdf from:

- ftp://ftp.princetoninstruments.com/Public/Manuals/Princeton Instruments/

Up-to-date copies of Acton manuals are available for download as a pdf from:

- ftp://ftp.princetoninstruments.com/Public/Manuals/Acton/

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Chapter 17: Troubleshooting

⚠ **CAUTION!** ————————————————————————
> If a sudden change in the baseline signal is observed, there may
> be excessive humidity within the CCD enclosure of the
> camera. Contact the factory for information about having the
> camera checked or repaired.

WARNING! ————————————————————————
Do not attach or remove any cables while the camera system is
powered on.

Recommended troubleshooting procedures are available for many issues that may occur
while working with a PI-MAX4 system. Refer to Table 17-1 for additional information.

Table 17-1: Issues with Recommended Troubleshooting Procedures

Issue	Refer to…
Alarm Sounds Repetitively	page 248
Alarm Sounds Sporadically	page 248
Baseline Signal Suddenly Changes by > 1000 ADU	page 248
Camera Is Not Responding	page 248
Camera Stops Working	page 249
Camera1 (or similar name) in Camera Name field	page 249
Cooling Troubleshooting	page 250
Data Loss or Serial Violation	page 251
Error Occurs at Computer Power Up	page 251
Ethernet Network is Not Accessible	page 252
Excessive Readout Noise	page 253
Gating Pulse Artifact Strings Displayed	page 254

17.1   Alarm Sounds Repetitively

Immediately reduce the light entering the camera. This can be done by switching **I.I.T.** switch on the back of the PI-MAX4 to **OFF** until you lower the source illumination, by decreasing the lens aperture, or by completely blocking the light into the camera window with a lens cap or equivalent until the light level has be lowered.

If the alarm sounds repetitively even when the illumination level is adequately low, switch the **I.I.T.** to **OFF** and turn off the PI-MAX4 power supply. Then contact the factory: this may indicate intensifier damage or another situation that requires immediate attention.

17.2   Alarm Sounds Sporadically

It is normal for the alarm to sound briefly when the high-voltage supply is first turned on. However, if the alarm sounds sporadically, contact the factory at once. This may indicate intensifier damage or another situation that requires immediate attention.

17.3   Baseline Signal Suddenly Changes by > 1000 ADU

There are two possible reasons for this change:

- The temperature setting has been changed. In this case, a change in baseline signal is normal.
- There may be excessive **humidity** in the CCD enclosure of the camera. If the temperature setting has not been changed and you observe a baseline signal change, turn off the system immediately. An excess humidity condition should be corrected promptly or permanent damage not covered by the Warranty could occur. Have the unit serviced by Princeton Instruments or an authorized service facility of Princeton Instruments.

17.4   Camera Is Not Responding

If this message pops up when you click on **OK** after selecting the Interface Type during **Hardware Setup** (under the WinX **Setup** menu,) the system has not been able to communicate with the camera. Check to see if the Controller has been turned ON and if the interface card, its driver, and the interface cable have been installed.

If the Camera is ON, the problem may be with the interface card, its driver, interrupt or address conflicts, or the cable connections.

If the interface card is not installed, close the application software and turn the PI-MAX4 power supply OFF. Follow the interface card manufacturer's installation instructions and cable the interface card to the **GIG-E** port on the rear of the camera. Then do a **Custom** installation of WinSpec/32 or WinView/32 with the appropriate interface component selected. Be sure to deselect the interface component that does not apply to your system.

If the interface card is installed in the computer and is cabled to the **GIG-E** port on the rear of the camera, close the application program and turn the camera OFF. Check the cable connections and secure the cables if connections are loose.

If the interface card was installed after the WinX application software has been installed, close the application program and do a **Custom** installation of WinSpec/32 or WinView/32 with the GigE interface component selected. Be sure to deselect the interface component that does not apply to your system.

17.5   Camera Stops Working

Problems with the host computer system or software may have side effects that appear to be hardware problems. If you are sure the problem is in the camera system hardware, begin with these simple checks:

- Turn off all AC power.
- Verify that all cables are securely fastened and that all locking screws are in place and all slide latches are in the latched position.
- Correct any apparent problems and turn the system on.
- If the system still does not respond, contact Customer Support.

17.6   Camera1 (or similar name) in Camera Name field

When the Camera Detection Wizard installs a new camera, the camera is automatically named "Camera#" (where # = 1, 2, or 3, depending on the number of cameras detected) This name will appear in the **Hardware Setup** title bar and as the active camera on the **Hardware Setup —> Controller/Camera** tab. See Figure 17-1

Figure 17-1: Camera1 in Camera Name Field
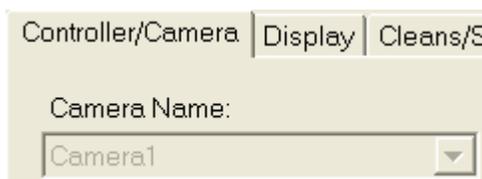
4411-0137_0141

If desired, a more specific name may be assigned to the camera by editing PVCAM.INI (located in the Windows directory.) The new name will then be used by the system until the Camera Detection Wizard is run again.

Perform the following procedure to change the default Camera Name:

1. Close the application program if it is running.
2. Using Notepad.exe, open PVCAM.INI from the **Windows** directory.
3. Edit the **Name** as shown in Figure 17-2.
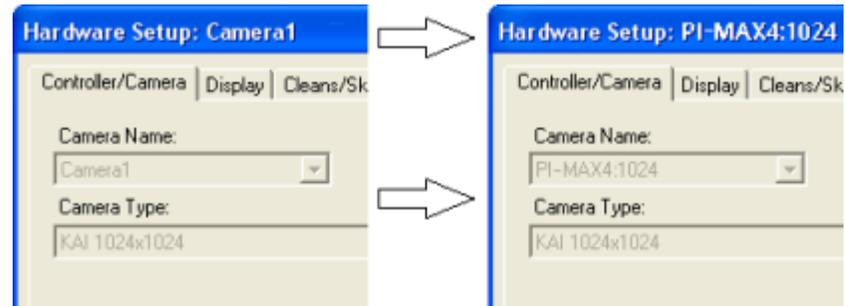
Figure 17-2: Editing Camera Name in Notepad
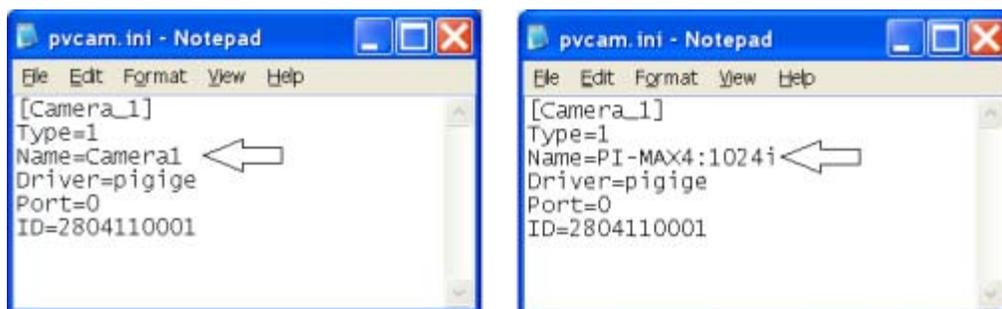
4411-0137_0142

4. Save the edited file.

5. The next time WinX is launched, the new name will be displayed on the Hardware Setup dialog. See Figure 17-3.

Figure 17-3: Updated Hardware Setup Dialog

4411-0137_0143

🔍 **NOTE:**

If the Camera Detection Wizard is launched and run at a later time, the name will be revert back to the default name (i.e., Camera1.)

17.7 Cooling Troubleshooting

This section provides recommended troubleshooting guidelines for cooling-related problems.

17.7.1 Temperature Lock Cannot be Achieved or Maintained.

Possible causes for not being able to achieve or maintain lock could include:

- Ambient temperature greater than +20°C.
  This condition affects TE-cooled cameras. If ambient is greater than +20°C, you will need to cool the camera environment or raise the set temperature.

- Airflow through the camera and/or circulator is obstructed.
  The camera needs to have approximately two (2) inches (50 mm) clearance around the vented covers. If there is an enclosure involved, the enclosure needs to have unrestricted flow to an open environment. The camera vents its heat out the side vents near the nose. The air intake is at the rear of the camera.

- A hose is kinked. Unkink the hose.

- Coolant level is low.
  Add 50:50 mix of ethylene glycol and water. Refer to manufacturer's instructions for adding coolant.

- There may be air in the hoses.
  Remove air and add 50:50 mix of ethylene glycol and water. Refer to manufacturer's instructions for removing excess air and adding coolant.

- Circulator pump is not working.
  If you do not hear the pump running when the circulator is powered on, turn off the circulator and contact the manufacturer's Customer Support.

- CoolCUBE$_{II}$
  The circulator is higher than the camera. Reposition the circulator so that it is
  6 inches (150 mm) or more below the camera. The vertical distance should not
  exceed 10 feet (3 m.) Typically, the camera is at table height and the circulator is on
  the floor.

- The target array temperature is not appropriate for the specific camera and CCD
  array.

- The camera's internal temperature may be too high.
  This may occur if the operating environment is particularly warm, if you are
  attempting to operate at a temperature colder than the specified limit, or if you have
  turned off the fan and are not circulating coolant through the camera. TE cameras
  are equipped with a thermal-protection switch that shuts the cooler circuits down if
  the internal temperature exceeds a preset limit. Typically, camera operation is
  restored automatically in about ten minutes. Although the thermo-protection switch
  will protect the camera, you are nevertheless advised to power down and correct the
  operating conditions that caused the thermal-overload to occur.

17.8   Data Loss or Serial Violation

You may experience either or both of these conditions if the host computer has been set up
with Power Saving features enabled. This is particularly true for power saving with regard
to the hard drive. Make sure that Power Saving features are disabled while you are running
WinView/32 or WinSpec/32.

17.9   Error Occurs at Computer Power Up

If an error occurs at boot up, either the Interface is not installed properly or there is an
address or interrupt conflict. Turn off the computer, try a new address or interrupt and
reinstall the card. Be sure the Interface is firmly mounted in the slot.

⚠ **CAUTION!** ────────────────────

Since interrupts and DMA channels cannot be shared, make
sure no other boards in your computer use this interrupt or
these DMA channels.

17.10 Ethernet Network is Not Accessible

When the Princeton Instruments software is installed, **all** Intel Pro/1000 interface card drivers found on the host computer are updated with the Intel Pro/1000 Grabber Adapter (Vision High-Performance IP Device) driver provided by Pleora Technologies, Inc. If this computer is connected to an Ethernet network via an Intel Pro/1000 card that does not use the Pleora driver, the network connection will be broken. The tool used to restore the network connection depends on whether you are using WinX (32-bit) or LightField (64-bit.)

17.10.1 LightField Applications

Perform the following procedure to install necessary drivers for LightField applications:

1. Locate the EbDriverTool64.exe file.

    This is typically located in the C:\Program Files\Common Files\Pleora directory. The EbDriverTool64.exe file may be located in a subsequent subdirectory.

2. Double-click on the file to launch the driver installation tool.

    The **eBUS Driver Installation Tool** dialog is displayed, similar to that shown in Figure 17-4.

Figure 17-4: eBUS Driver Installation Tool Dialog for LightField
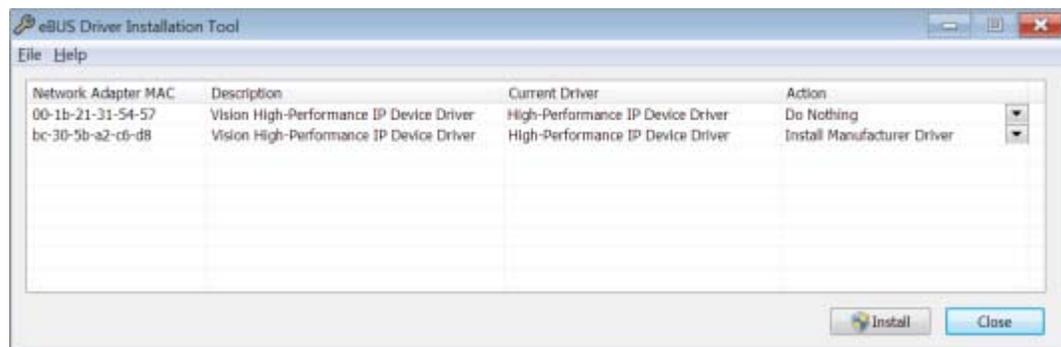
4411-0137_0145

3. From the list of devices, identify the appropriate Ethernet card. Within the **Action** column, select **Install Manufacturer Driver** from the appropriate pull-down menu.

4. Click **Install** to load the selected driver.

5. After the installation it may be necessary to reboot the computer. If prompted to do so, either:

    •   Click **Yes** to initiate the reboot.

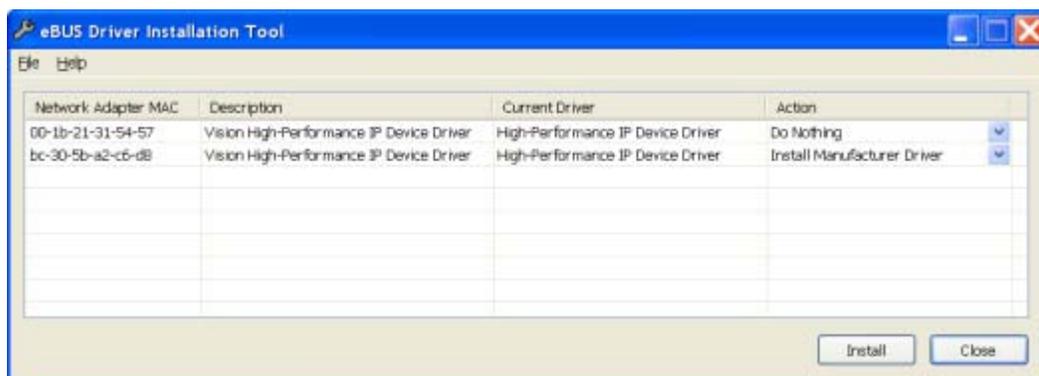   •   Click **No** to delay the reboot.

        When delaying the reboot, it may be necessary to manually close the **eBUS Driver Installation Tool** dialog. Reboot the computer when convenient.

6. Verify that the network connection has been re-established. If a reboot was required, wait until the reboot has occurred before verifying the connection.

17.10.2 WinX Applications

Perform the following procedure to install necessary drivers for WinX applications:

1. Locate the EbDriverTool**32**.exe file.

   - Download the **EbDriverTool32.exe** file to the host computer from ftp:// ftp.princetoninstruments.com/public/Software/Official/WinX32/GigE/

   - Or open the default Pleora directory. Typically it is located at `C:\Program Files\Common Files\Pleora`. The `EbDriverTool32.exe` (or `EbDriverTool.exe`) file may be in a subdirectory.

2. Double-click on the file to launch the driver installation tool.

   The **eBUS Driver Installation Tool** dialog is displayed, similar to that shown in Figure 17-5.

Figure 17-5: eBUS Driver Installation Tool Dialog for WinX

4411-0137_0144

3. From the list of devices, identify the appropriate Ethernet card. Within the **Action** column, select **Install Manufacturer Driver** from the appropriate pull-down menu.

4. Click **Install** to load the selected driver.

5. After the installation it may be necessary to reboot the computer. If prompted to do so, either:

   - Click **Yes** to initiate the reboot.

   - Click **No** to delay the reboot.

     When delaying the reboot, it may be necessary to manually close the **eBUS Driver Installation Tool** dialog. Reboot the computer when convenient.

6. Verify that the network connection has been re-established. If a reboot was required, wait until the reboot has occurred before verifying the connection.

17.11 Excessive Readout Noise

Excessive readout noise with the intensifier off indicates possible moisture accumulation in the CCD. This should be corrected promptly or permanent damage not covered by the Warranty could occur.

Normal camera noise is a function of the gain setting and temperature as well as CCD type, but is typically in the range of 1-50 ADU_{rms} (6 -300 ADU_{p-p}.) This is in addition to offset that typically is about 600 counts. Moisture accumulation produces a coarser noise with many spikes ≥ 300 ADU. If these types of spikes occur, especially after the camera has been in use for an extended period, turn off the system immediately. Have the unit serviced by Princeton Instruments or an authorized service facility of Princeton Instruments.

17.12 Gating Pulse Artifact Strings Displayed

PI-MAX4:512/1024 EM(B) cameras may experience noise in the form of gating pulse artifacts, sometimes referred to as Machine Gun" dots, during readout. Figure 17-6 shows a typical display with numerous gating pulse artifact strings displayed.

Figure 17-6: Typical Diagonal Line of Gating Pulse Artifacts
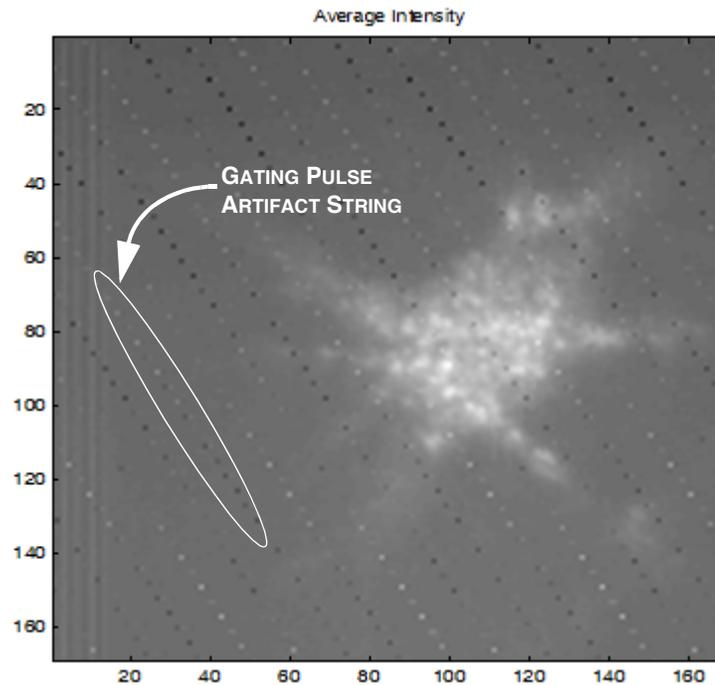
The "machine gun" effect may be observed when a PI-MAX4:512/1024 EM(B) camera has been configured for:

- A very large number of on-chip accumulations;
- Interline Overlapped Mode
  In this mode, as one frame of data is being read out, the intensifier is being gated and the next frame of data is being exposed. The gating pulse artifacts are the result of a 200 V gate pulse's being emitted approximately 1 inch from the camera's CCD. Refer to Section 5.8.1, Interline CCD Readout, on page 71 for additional information.

Recommended solutions include:

- Configure the system for fewer on-chip accumulations.
- Operate in Full-Frame mode.
  This will prevent gating during readout. Refer to Section 5.8.2, Full-Frame CCD Readout, on page 74 for additional information.
- Increase the EM Gain so that pulse artifact levels are minimized while desired signal levels are amplified. Refer to Section 14.1.2, EM Gain Mode, on page 208 for additional information.

Appendix A: Technical Specifications

⚠ **CAUTION!** ————————————————————————

All specifications provided in this appendix are **subject to change**. For complete and up-to-date information about performance, available options, and accessories, contact the factory or visit the Princeton Instruments website at www.princetoninstruments.com.

This appendix provides technical information and specifications for the family of PI-MAX4 cameras and, where appropriate, optional accessories. Information pertaining to all cameras is provided in the early sections, while device-specific information is provided in later sections.

A.1 Mechanical Dimensions

Refer to Appendix B, Outline Drawings, for camera-specific dimensions.

A.2 Power Specifications

All DC voltages required by PI-MAX4 cameras are generated by an external power supply and then delivered to the camera using a custom power cable.

Refer to Table A-1 for input power specifications for the external PI-MAX4 Power Supply.

Table A-1: Input Power Specifications: External PI-MAX4 Power Supply

Parameter	Specification			Unit
	Minimum	**Nominal**	**Maximum**	
Input Voltage	90	100 120 220 240	264	V_{AC}
Input Frequency	47	50 60	63	Hz
Input Power	—	—	400	W

A.3 Environmental Specifications

Refer to Table A-2 for environmental specifications for the PI-MAX4 system.

Table A-2: PI-MAX4 Environmental Specifications

Parameter	Specification		
	Minimum	Nominal	Maximum
Storage Temperature	-20°C	—	+55°C
Operating Temperature	5ºC	—	+30ºC
Operating Ambient Relative Humidity	<80% (non-condensing)		
Operating Ambient Temperature[a]	0°C	—	+30°C
Supplemental Cooling Water Flow Rate[b]	1 - 3 liters per minute		

a. Although operation to -25°C is achievable, operation below 0°C is not guaranteed.
b. Circulating water enhances cooling performance but is not required.

A.4 Intensifier Specifications

For information about compatible intensifiers, refer to the Princeton Instruments website:

http://www.princetoninstruments.com

A.5 CCD Specifications

Refer to Table A-3 for CCD array specifications for Electron Multiplied PI-MAX4 detectors.

Table A-3: CCD Array Specifications for Electron Multiplied PI-MAX4 Detectors

Parameter	512EM	512EM(B)	1024EM	1024EM(B)
CCD	e2v CCD97	e2v CCD97	e2v CCD201	e2v CCD201
Illumination	Front	Back	Front	Back
Architecture	Frame Transfer	Frame Transfer	Frame Transfer	Frame Transfer
Resolution	512 x 512	512 x 512	1024 x 1024	1024 x 1024
Pixel Size	16 μm x 16 μm	16 μm x 16 μm	13 μm x 13 μm	13 μm x 13 μm
Active Area	8.192 mm x 8.192 mm	8.192 mm x 8.192 mm	13.3 mm x 13.3 mm	13.3 mm x 13.3 mm
Readout Ports	2	2	2	2
Frame Rate[a] (full frame)	≥ 32 fps @10 MHz	≥ 32 fps @10 MHz	≥ 8 fps @10 MHz	≥ 8 fps @10 MHz
EM Mode Readout Rates	5 MHz, 10 MHz	5 MHz, 10 MHz	5 MHz, 10 MHz	5 MHz, 10 MHz
Standard Mode Readout Rates	500 kHz, 1 MHz, 5 MHz	500 kHz, 1 MHz, 5 MHz	500 kHz, 1 MHz, 5 MHz	500 kHz, 1 MHz, 5 MHz
Deepest Cooling Temperature at +20°C ambient	-25°C (air) -30°C (liquid)	-25°C (air) -30°C (liquid)	-25°C (air) -30°C (liquid)	-25°C (air) -30°C (liquid)

a. Binning-dependent

Refer to Table A-4 for CCD array specifications for non-EM PI-MAX4 detectors.

Table A-4:   CCD Array Specifications for non-EM PI-MAX4 Detectors

Parameter	1024i	1024f	1024i-RF	2048f	1024 x 256
CCD	KAI-1003	e2v CCD47-10	KAI-1003	e2v CCD42-40	e2v CCD30-11
Illumination	Front	Front	Front	Front	Front
Architecture	Interline	Full-Frame	Interline	Full-Frame	Full-Frame
Resolution	1024 x 1024	1024 x 1024	1024 x 1024	2048 x 2048	1024 x 253
Pixel Size	12.8 µm x 12.8 µm	13.0 µm x 13.0 µm	12.8 µm x 12.8 µm	13.5 µm x 13.5 µm	26.0 µm x 26.0 µm
Active Area	13.1 mm x 13.1 mm	13.3 mm x 13.3 mm	13.1 mm x 13.1 mm	27.6 mm x 27.6 mm	18.0 mm x 6.6 mm[a] 25.0 mm x 6.6 mm[b]
Readout Ports	2	2	2	2	1
Frame Rate[c] (full frame)	$\geq$ 26 fps @32 MHz	$\geq$ 7.69 fps @10 MHz	$\geq$ 26 fps @32 MHz	$\geq$ 7.69 fps @10 MHz	—
Spectral Rate[d]	—	—	—	—	284 fps @ 2 MHz
Standard Mode Readout Rates	4 MHz, 16 MHz, 32 MHz	1 MHz, 2 MHz, 10 MHz	4 MHz, 16 MHz, 32 MHz	500 kHz, 1 MHz, 5 MHz	500 kHz, 1 MHz, 2 MHz
Deepest Cooling Temperature at +20°C ambient	-25°C (air) -35°C (liquid)	-25°C (air) -35°C (liquid)	-25°C (air) -35°C (liquid)	-20°C (air) -35°C (liquid)	-25°C (air) -35°C (liquid)

a. Using 18 mm intensifier.
b. Center region using 25 mm intensifier.
c. Binning-dependent
d. Full vertical binning.

A.6 AUX I/O Interface

The AUX I/O interface provides access to the trigger function, DAC, and TTL signals via a rear panel connector and an AUX I/O cable that is supplied with each PI-MAX4 system. This section provides pinout information for both the rear panel AUX I/O connector as well as the AUX I/O Cable.

Table A-5 provides TTL signal-specifications for the AUX I/O interface.

Table A-5:   AUX I/O Interface TTL Signal Specifications

Parameter	Specification			Unit
	Minimum	**Nominal**	**Maximum**	
V_{IN} (logic 1)	2.4	—	—	V_{DC}
V_{IN} (logic 0)	—	—	0.9	V_{DC}
Rise Time			≤ 40	ns
Duration	≥ 100			ns

The AUX I/O connector is located on the rear of the PI-MAX4 chassis. It is a female, DB26, high-density connector.

Figure A-1 illustrates the pinout of the AUX I/O connector, viewed from the rear panel of the PI-MAX4 chassis, with each contact/pin identified by its pin number.

Figure A-1:   AUX I/O Connector Pinout
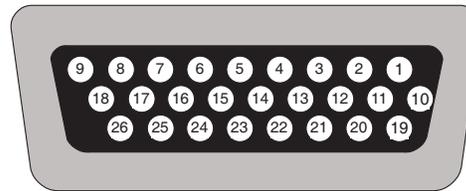
4411-0137_0147

Table A-6 provides complete information about each AUX I/O pin and signal sorted by pin number.

Table A-6:   AUX I/O Connector Pinout and Signal Descriptions (Sheet 1 of 2)

Pin #	Signal Name	Description
1	T0 Output	LVCMOS FPGA output with limited ESD protection, goes high at T0. Indicates a trigger has been received.
2	Pre-Trigger Input	LVCMOS ESD-protected input. Pre-Trigger is an optional signal that may be used to terminate the continuous cleans instruction operation. In ordinary operation there is a one clean cycle jitter between the trigger and the finish of cleaning (i.e., the clean cycle in process must be completed.) A rising edge will cause a pre-trigger. **NOTE:** The camera must already be in Acquire mode before the pre-trigger is sent to the input.
3	GND	System chassis ground. Any external circuitry intended to interface with the trigger control signals must reference this ground connection.
4	Lockout Output	LOW indicates I.I.T. is locked off.

Table A-6:   AUX I/O Connector Pinout and Signal Descriptions (Sheet 2 of 2)

Pin #	Signal Name	Description
5	—	Not Used
6	GND	System chassis ground. Any external circuitry intended to interface with the trigger control signals must reference this ground connection.
7	SyncMASTER1 Output	LVCMOS Active high. User-configurable output. SyncMASTER1 can be user-configured to provide a user-specified continuous frequency output (not just when the camera is taking data) until halted by the user. In this configuration, the output could be used to synchronize a laser, shutter, AOTF… with the camera.
8	General Purpose Input 0	Reserved for future use as general LVCMOS input limited ESD protection.
9	L_Shutter (via 1 kΩ)	Do Not Use.
10	Source Comp	Reserved for future Use. Analog Input.
11	Logic GND	Do Not Use.
12	+5.9 V	+5.9 V thru 100 Ω
13	—	Not Used
14	General Purpose Output 3	Requires a 1 kΩ resistor. Reserved
15	General Purpose Output 2	Requires a 1 kΩ resistor. Reserved
16	General Purpose Output 1	Requires a 1 kΩ resistor. Reserved
17	SyncMASTER2 Output	Requires a 1 kΩ resistor.
18	GND	System chassis ground. Any external circuitry intended to interface with the trigger control signals must reference this ground connection.
19	—	Not Used
20	GND	System chassis ground. Any external circuitry intended to interface with the trigger control signals must reference this ground connection.
21	General Purpose Input 2	Requires a 1 kΩ resistor. Reserved
22	General Purpose Input 1	Requires a 1 kΩ resistor. Reserved
23	SyncMASTER2 (via 10 Ω)	Requires a 10 Ω resistor. Programmable continuous frequency output (100 ns - 6.55 ms delay from SyncMASTER1) synchronize external devices with PI-MAX4 (e.g. Q-switch.)
24	—	Not Used
25	GND	System chassis ground. Any external circuitry intended to interface with the trigger control signals must reference this ground connection.
26	General Purpose Input 3	Requires a 1 kΩ resistor. Reserved

A.6.1   AUX I/O Cable

Each PI-MAX4 system includes an AUX I/O cable that provides convenient access to several system signals. The AUX I/O interface cable is comprised of a male DB26 connector on one end, and five female BNC cables on the other end, each of which provides access to a system signal.

Figure A-2 illustrates a typical cable.

Figure A-2:   AUX I/O Interface Cable (Part Number 6050-0660)

4411-0137_0146

Table A-7 provides the color code and pinout information for the AUX I/O interface cable.

Table A-7:   AUX I/O Interface Cable Pinout and Signal Information

Cable Color	BNC Conductor	Signal Name	DB26 Pin #
Red	Center	T0 OUT	1
	Shield	Ground	3
Green	Center	PRE-TRIG IN	2
	Shield	Ground	6
Blue	Center	SyncMASTER1	7
	Shield	Ground	18
Gray	Center	GP INPUT 0	8
	Shield	Ground	20
Black	Center	SyncMASTER2	23
	Shield	Ground	25

A.7   CoolCUBE$_{II}$ Circulator Specifications

Closed Loop System

- **Hoses**

  Two 3 m [10 ft] hoses may be supplied with the PI-MAX4 camera system. These hoses are comprised of a 0.3 m [2 ft] piece of ¼" ID hose joined by a reducer to a 2.4 m [8 ft] piece of 3/8" ID hose.

  Refer to the coolant circulator's specifications regarding circulator-compatible hose fittings. If a Princeton Instruments CoolCUBE$_{II}$ circulator is ordered with the camera, hoses are supplied with appropriate CoolCUBE$_{II}$ connectors.

  NOTE:

  Part numbers for the hose, reducer fitting, and CoolCUBE$_{II}$ fitting are:

  - **Hose:** McMaster MCM # 5624K11 (1/4 ID) and #5624K12 (3/8 ID);
  - **Reducer Fitting:** McMaster # MCM 91355K32 (3/8-1/4 Reducer);
  - **Fitting:** CPC # NS6D17006 (3/8" Quick Disconnect.)

- **Coolant:** 50:50 mixture of ethylene glycol and water at 23°C
- **Dimensions:** Refer to Appendix B, Outline Drawings, on page 263 for complete information.
- **Circulator Weight (Filled):** 6.0 lbs (2.7 kg)
- **Hose Weight (Filled):** 3.0 lbs (1.4 kg) per hose

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Appendix B: Outline Drawings

📄**NOTE:** ─────────────────────────────────────

Dimensions are in inches and [mm] unless otherwise noted.
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B.1   PI-MAX4: 1024i/1024f/2048f/1024x256

Figure B-1:   Outline Drawing: PI-MAX4: 1024i/1024f/2048f/1024x256 with C-mount Adapter
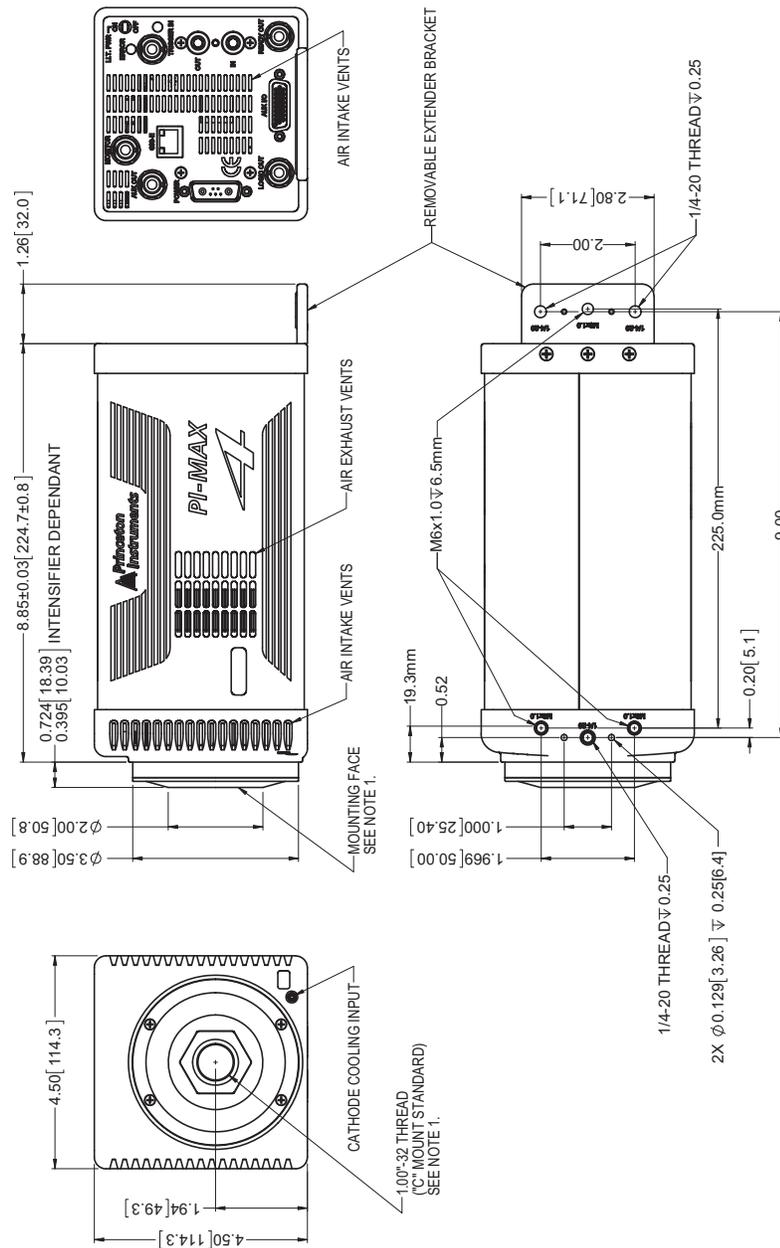
4411-0137_0148

Figure B-2:   Outline Drawing: PI-MAX4: 1024i/1024f/2048f/1024x256 with F-mount Adapter
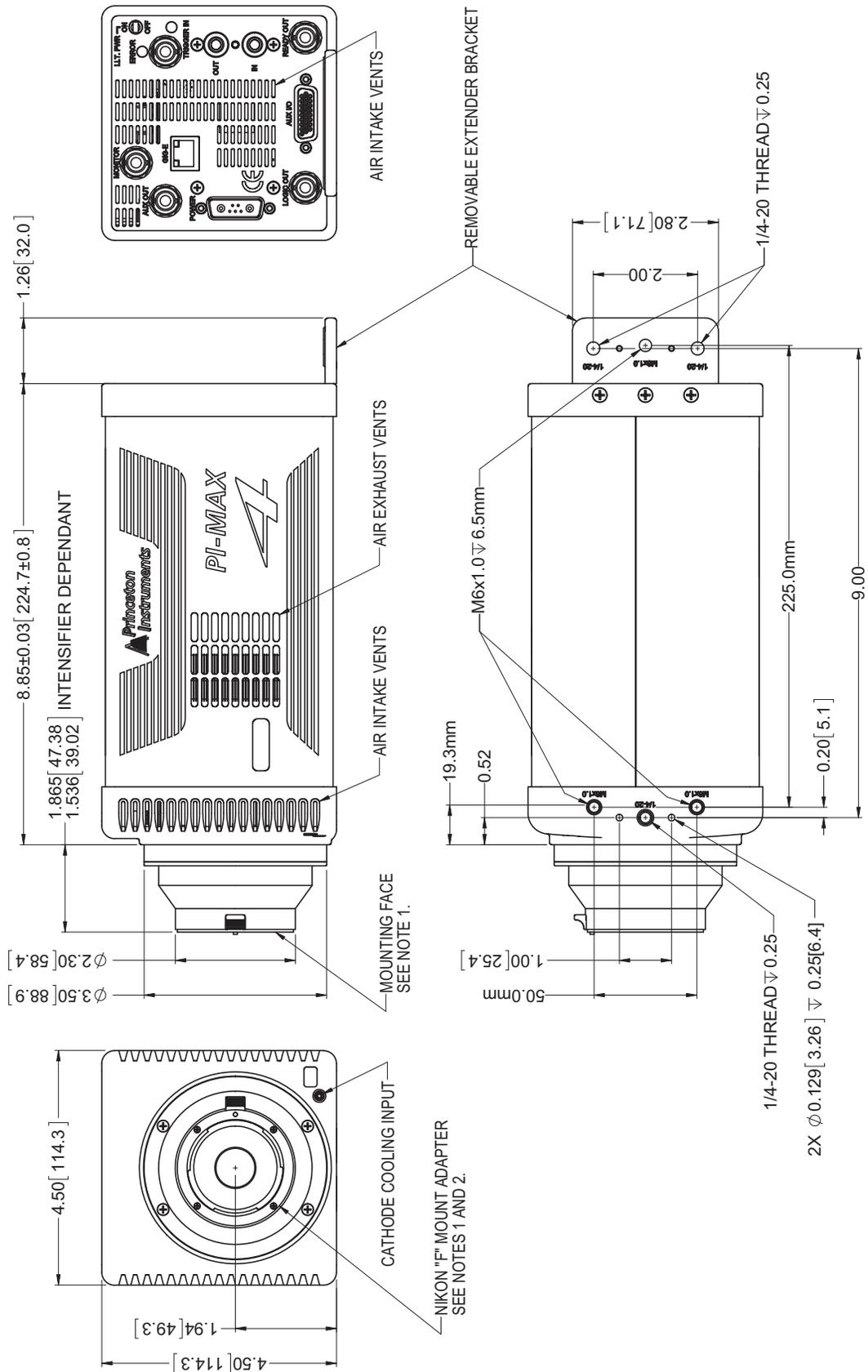
NOTES:
1. MOUNTING FACE TO IMAGE PLANE IS FACTORY PRESET
   TO OPTICAL DISTANCE OF 1.831 ±0.010 [46.50 ±0.25].

2. LENS RELEASE TRIGGER ORIENTATION CAN BE
   ROTATED IN 180 ° INCREMENTS.

4411-0137_0149

Figure B-3:   Outline Drawing: PI-MAX4: 1024i/1024f/2048f/1024x256 with Spectroscopy-mount Adapter

4411-0137_0150

B.2   PI-MAX4: 512 EM/512 EM(B)

Figure B-4:   Outline Drawing: PI-MAX4: 512 EM/512 EM(B) with C-mount Adapter

NOTES:

1. MOUNTING FACE TO IMAGE PLANE IS FACTORY PRESET
   TO OPTICAL DISTANCE OF 0.690 ± 0.010 [17.53 ± 0.25]

2. DIMENSIONS IN INCHES [mm]

3. TOLERANCES: ± 0.01 [±0.25]

4. WEIGHT: CAMERA   6.86 lbs (3.12 kg)
            POWER SUPPLY   4.1 lbs (1.87 kg)

4411-0137_0151

Figure B-5:   Outline Drawing: PI-MAX4: 512 EM/512 EM(B) with F-mount Adapter

4411-0137_0152

Figure B-6:   Outline Drawing: PI-MAX4: 512 EM/512 EM(B) with Spectroscopy-mount Adapter

4411-0137_0153

B.3   PI-MAX4 Power Supply

Figure B-7:   Outline Drawing: PI-MAX4 Power Supply

4411-0137_0154
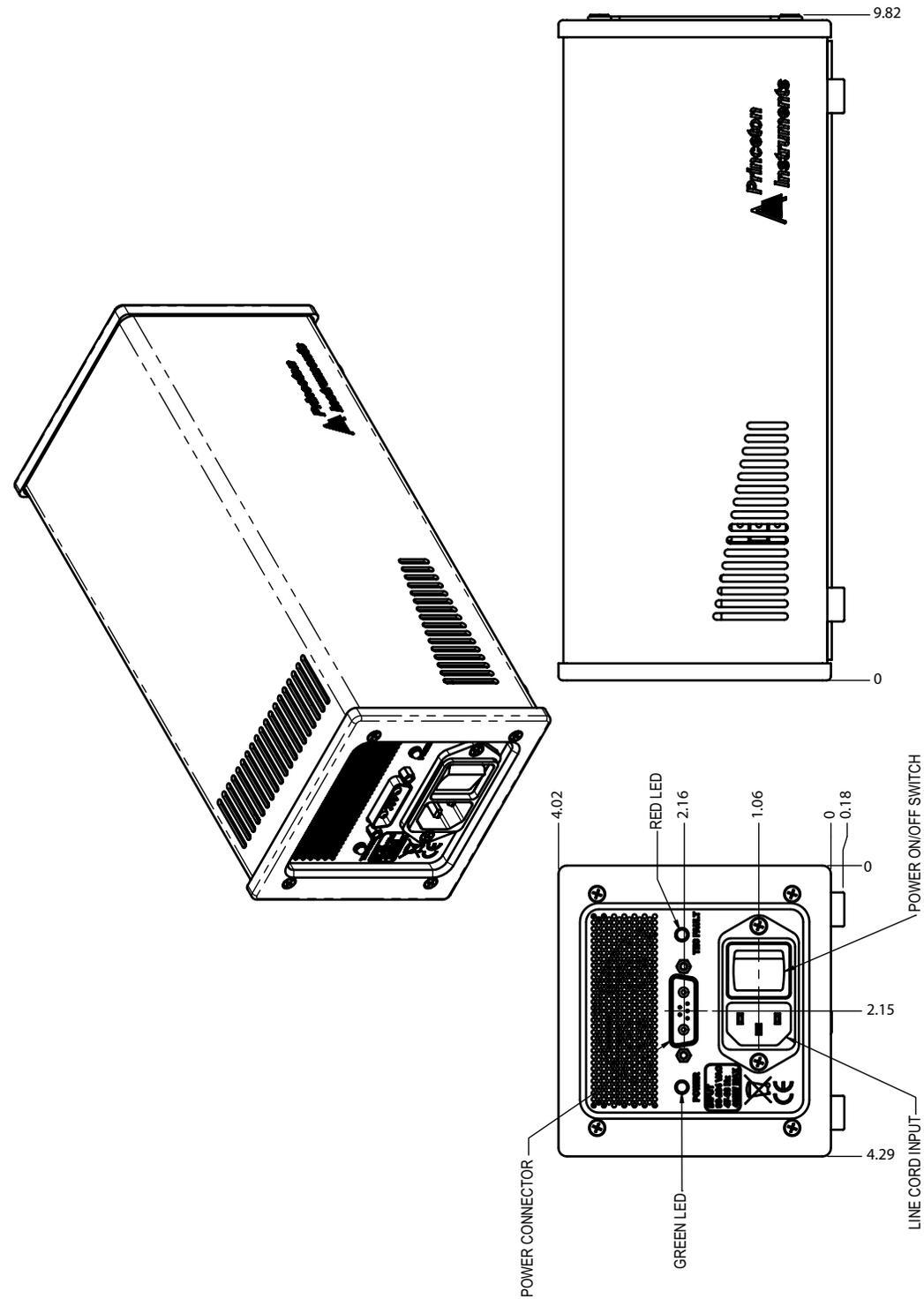
B.4   PI-MAX4: 1024i-RF

Figure B-8:   Outline Drawing: PI-MAX4: 1024i-RF with C-mount Adapter
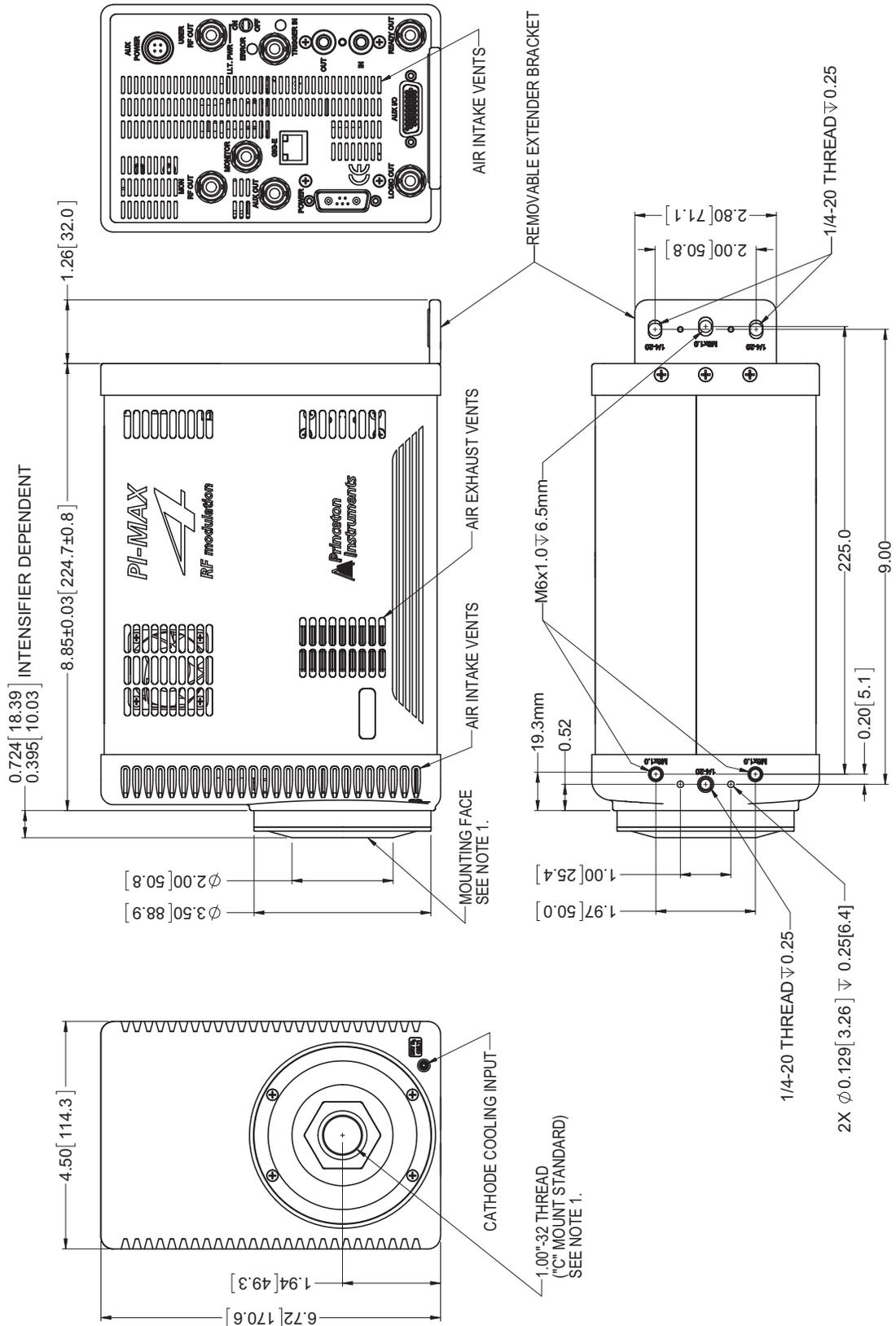
4411-0137_0155

Figure B-9:   Outline Drawing: PI-MAX4: 1024i-RF with F-mount Adapter

4411-0137_0156

Figure B-10: Outline Drawing: PI-MAX4: 1024i-RF with Spectroscopy-mount Adapter

B.5   PI-MAX4: 1024i-RF Power Supply

Figure B-11: Outline Drawing: PI-MAX4: 1024i-RF Power Supply

4411-0137_0158
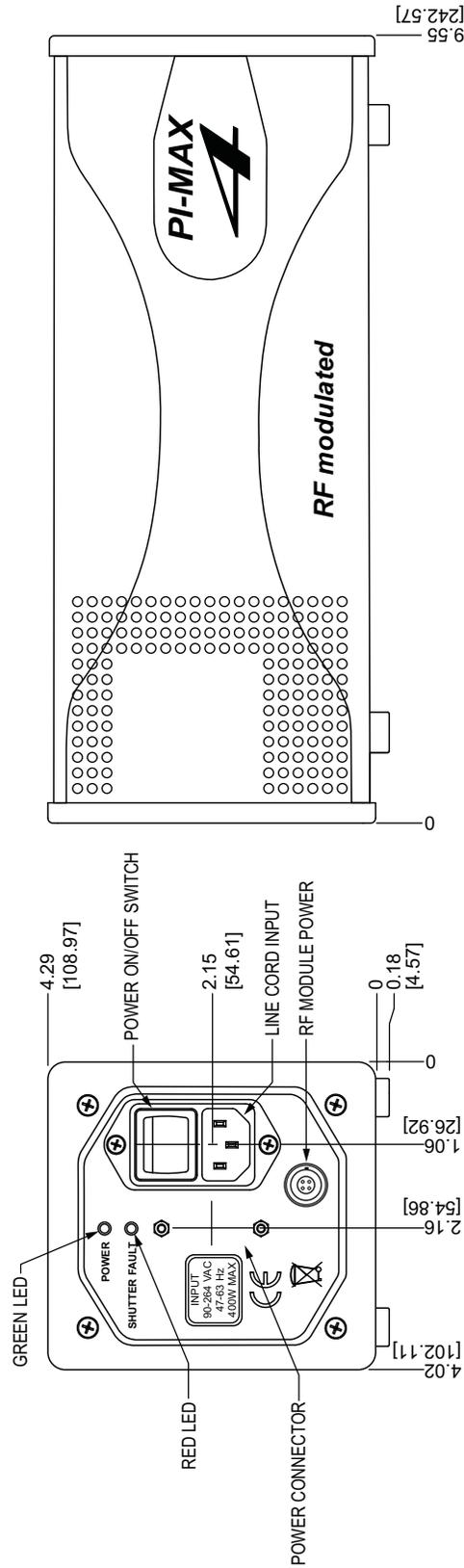
B.6 CoolCUBE_{II} Circulator

Figure B-12: Outline Drawing: CoolCUBE_{II} Circulator

4411-0137_0159
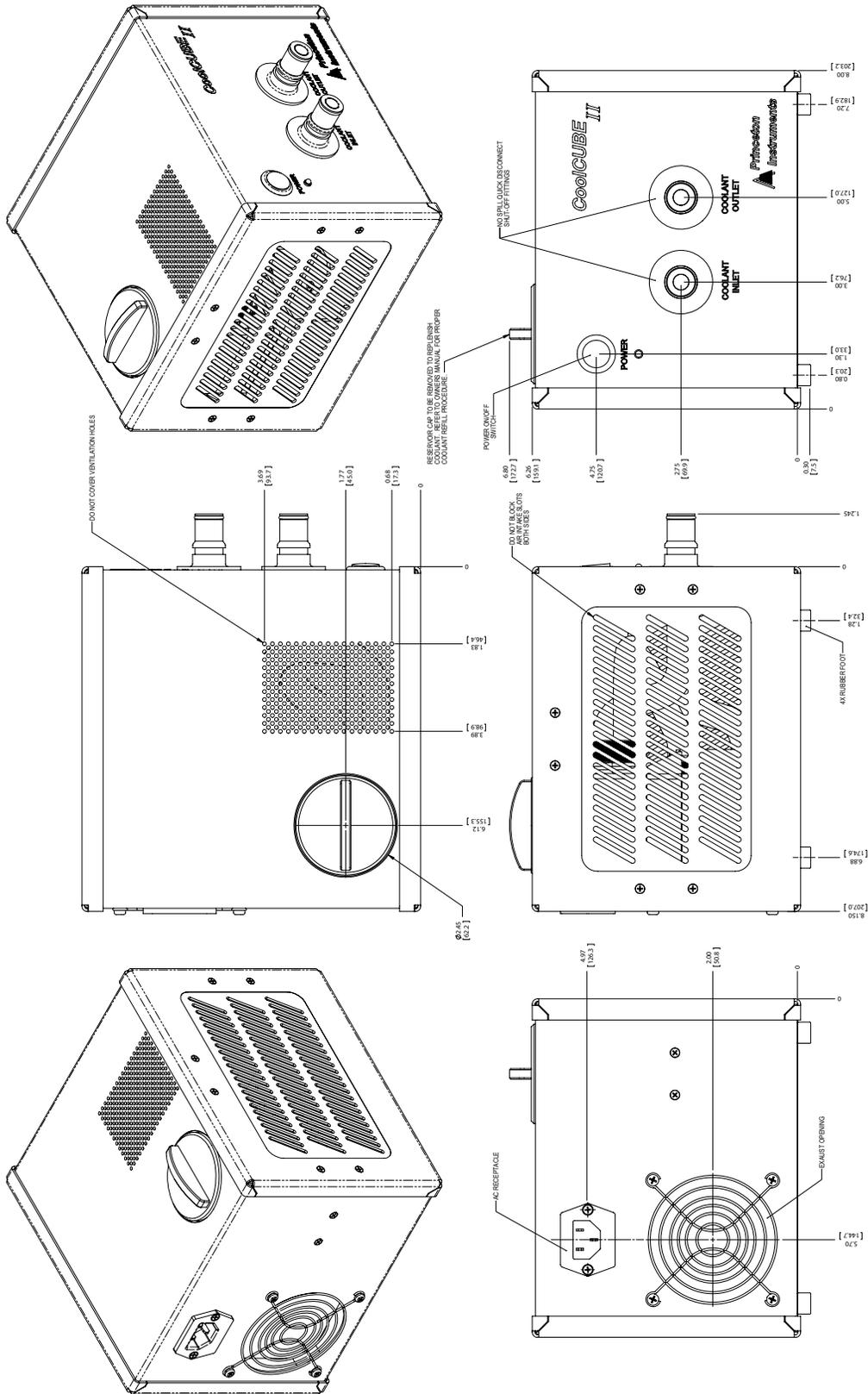
Appendix C: WinX/LightField Cross Reference

This appendix provides cross reference information for terminology used within the WinX and LightField application software packages.

C.1 WinX-to-LightField Terminology

Refer to Table C-1 for a list of WinX terms and their corresponding LightField terms.

Table C-1:   WinX-to-LightField Cross Reference (Sheet 1 of 2)

WinX Term	LightField Term
Active Rows Parallel to Shift Register	Active Height
Active Shift Register Columns	Active Width
ADC Rate	Speed
ADC Resolution	Bit Depth
Continuous Cleans	Clean Until Trigger
Controller Gain	Analog Gain
Custom Chip	Custom Sensor
Custom Timing	Custom Timing
Disabled Closed (Shutter)	Always Closed (Shutter)
Disabled Open (Shutter)	Always Open (Shutter)
Dual Trigger Mode	Shift Per Trigger
Easy Bin	Sensor Readout Region expander functions
Edge Trigger	Trigger Determined By
External Sync	Readout Per Trigger
F.T. Dummies or Frame Transfer Dummies	Active Area: Top Margin
Focus	Preview or Run
Free Run	No Response
Logic Out	Output Signal
Logic Out: Logic 0	Output Signal: Always Low
Logic Out: Logic 1	Output Signal: Always High
Logic Out: Not Ready	Output Signal: Busy
Logic Out: Not Scan	Output Signal: Not Reading Out

Table C-1:   WinX-to-LightField Cross Reference (Sheet 2 of 2)

WinX Term	LightField Term
Logic Out: Shutter	Output Signal: Shutter Open
Minimum Block Size	Final Section Height
Normal Shutter	Normal (Shutter)
Number of Blocks	Final Section Count
Number of Cleans	Number of Clean Cycles
Number of Strips per Clean	Clean Cycle Height
Post-Dummy Rows Parallel to Shift Register	Active Area: Bottom Margin
Post-Dummy Shift Register Columns	Active Area: Right Margin
Pre-Dummy Rows Parallel to Shift Register	Active Area: Top Margin
Pre-Dummy Shift Register Columns	Active Area: Left Margin
PreOpen (Shutter)	Open Before Trigger (Shutter)
Readout Port	Quality
Shutter Close Compensation Time	Closing Delay
Shutter Control	Shutter Mode
Shutter Open Compensation Time	Opening Delay
Single Trigger Mode (DIF)	Readout Per Trigger
Skip Serial Register Clean (deselected)	Clean Serial Register
Target Temperature	Temperature Setpoint
Timing Mode	Trigger Response

C.2 LightField to WinX

Refer to Table C-2 for a list of LightField terms and their corresponding WinX terms.

Table C-2:   LightField-to-WinX Cross Reference (Sheet 1 of 2)

LightField Term	WinX Term
Active Area: Bottom Margin	Post-Dummy Rows Parallel to Shift Register
Active Area: Left Margin	Pre-Dummy Shift Register Columns
Active Area: Right Margin	Post-Dummy Shift Register Columns
Active Area: Top Margin	F.T. Dummies or Frame Transfer Dummies
Active Area: Top Margin	Pre-Dummy Rows Parallel to Shift Register
Active Height	Active Rows Parallel to Shift Register
Active Width	Active Shift Register Columns
Always Closed (Shutter)	Disabled Closed (Shutter)
Always Open (Shutter)	Disabled Open (Shutter)
Analog Gain	Controller Gain
Bit Depth	ADC Resolution
Clean Cycle Height	Number of Strips per Clean
Clean Serial Register	Skip Serial Register Clean (deselected)
Clean Until Trigger	Continuous Cleans
Closing Delay	Shutter Close Compensation Time
Custom Sensor	Custom Chip
Custom Timing	Custom Timing
Final Section Count	Number of Blocks
Final Section Height	Minimum Block Size
No Response	Free Run
Normal (Shutter)	Normal Shutter
Number of Clean Cycles	Number of Cleans
Open Before Trigger (Shutter)	PreOpen (Shutter)
Opening Delay	Shutter Open Compensation Time
Output Signal	Logic Out
Output Signal: Always High	Logic Out: Logic 1
Output Signal: Always Low	Logic Out: Logic 0
Output Signal: Busy	Logic Out: Not Ready
Output Signal: Not Reading Out	Logic Out: Not Scan
Output Signal: Shutter Open	Logic Out: Shutter

Table C-2:   LightField-to-WinX Cross Reference (Sheet 2 of 2)

LightField Term	WinX Term
Preview	Focus
Quality	Readout Port
Readout Per Trigger	External Sync
Readout Per Trigger (DIF)	Single Trigger (DIF)
Sensor Readout Region expander functions	Easy Bin
Shift Per Trigger (DIF)	Dual Trigger Mode (DIF)
Shutter Mode	Shutter Control
Speed	ADC Rate
Temperature Setpoint	Target Temperature
Trigger Determined By	Edge Trigger
Trigger Response	Timing Mode

Appendix D: Extender Bracket Kit

An Extender Bracket kit (part number 2530-0085) is shipped with each PI-MAX4. After securing the bracket at the rear of the PI-MAX4, you can mount the PI-MAX4 to any laboratory table with either 25 mm or 1 inch hole spacing.

Perform the following procedure to secure the plate to the camera:

1. Remove the extender bracket and the three (3) 6-32x1/4" flathead screws from the bag.

2. Turn the camera upside down.

3. With the rear of the camera facing you, place the tongue of the bracket into the cutout under the now topmost edge. The text on the bracket should be visible.

4. Secure the plate with the three screws.

5. Turn the camera right side up and secure it to the laboratory table. If you will be using one or more mounting holes at the bottom front of the camera, tighten the fastener(s) there before tightening down the fastener(s) at the extender bracket.

See Figure D-1.
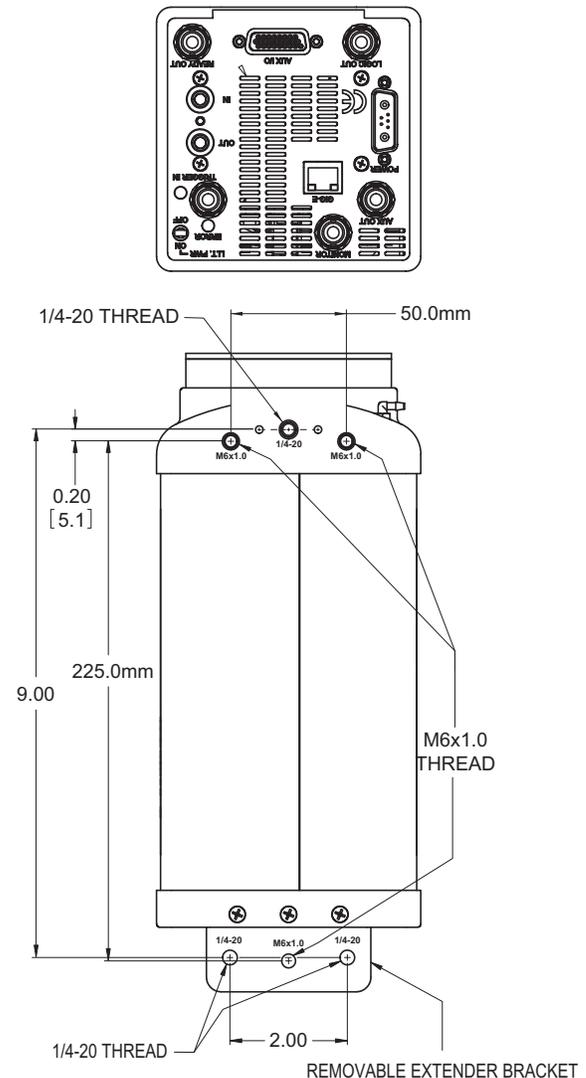
4411-0137_0171

Figure D-1:   Extender Bracket Kit Mounted to a PI-MAX4

📖 **NOTE:**

The table mounting holes in the plate are elongated to allow for tolerance variations.

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Appendix E: C- and F-Mount Information

This appendix provides information necessary in order to use C- and F-mount lenses with a
PI-MAX4 camera. Both types of lenses typically have provisions for focusing and aperture
adjustment, with the details varying according the make and model of the lens being used.

> **WARNING!**
> Before installing a lens, always begin with the lens stopped all the
> way down (i.e., the largest f/ stop number,) in order to minimize the
> risk of overloading the intensifier.

E.1   C-Mount Lens Information

This section provides information about mounting and removing a C-mount lens.

E.1.1   Installation

C-mount lenses simply screw **clockwise** into the threaded lens mount at the front of the
camera.

> ⚠ **CAUTION!**
> When mounting a C-mount lens, be sure to tighten it securely
> by hand - never use any tools.

E.1.2   Removal

When removing a C-mount lens, rotate the lens counterclockwise until it is free of the
mount.

E.2 F-Mount Lens Adapter

Figure E-1 illustrates a typical F-Mount, or Nikon, lens adapter.

Figure E-1:   F-Mount (Nikon) Lens Adapter

Lens release lever
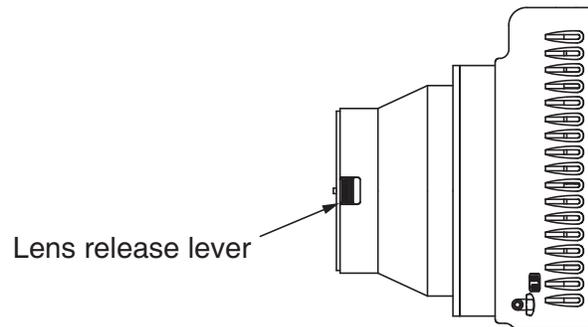
4411-0137_0173

E.2.1   Installation

Perform the following procedure to install an F-mount lens onto a PI-MAX4 camera:

1. Locate the large indicator dot on the side of the lens.
2. Locate the corresponding dot on the front side of the camera lens mount.
3. Line up these dots and slide the lens into the mount.
4. Turn the lens **counterclockwise** until a click is heard. This click indicates that the lens is securely locked in place.

E.2.2   Removal

Perform the following procedure to remove an F-mount lens:

1. Locate and depress the locking lever on the mount while rotating the lens clockwise.
2. Once the lens is free, pull it away from the adapter.

E.3   Camera Orientation

In general, a PI-MAX4 can be mounted at any attitude or angle, and the camera can rest on any secure surface.

Take care not to block the ventilation openings.

⚠ CAUTION! ───────────────────

When an F-mount lens has been installed on the PI-MAX4, **NEVER** mount the camera **nose-up** such that the lens mount would be required to support the camera's weight. The F-mount is not designed to sustain the weight of the camera in this orientation and the camera may break free.

If this orientation is required, additional support for the camera must be provided.

Should the camera be mounted in the nose-up position beneath a table, take care to protect the mounting components from lateral stresses, such as might occur should someone accidentally bump the camera with a knee while working at the table. One solution to this problem would be to install a barrier between the camera and operator to prevent any accidental contact.

There are no special constraints on nose-down operation. Again, however, good operating practice might make it advisable to take steps to prevent accidental contact from unduly stressing the mounting components.

WARNING! ───────────────────

Always begin with the lens stopped all the way down (i.e., largest f/stop number,) to minimize the risk of overloading the intensifier.

E.4   Focusing C- and F-Mount Lenses

There is no difference between focusing considerations for an F-mount lens and a C-mount lens. Simply rotate the lens-focusing ring for the sharpest observed image. The lens will show maximum focus sensitivity at full aperture (lowest f-stop setting.) Once the point of optimum focus is obtained, you may wish to adjust the lens aperture to f/8 or f/11, that is, somewhere near mid-range aperture, where the lens will probably be sharper than it is with the lens aperture completely open. Some readjustment of the Exposure Time may be required to achieve the most pleasing image.

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Appendix F: Spectrograph Mount Information

This appendix provides information about mounting a PI-MAX4 with spectroscopy-mount adapter to an Acton SpectraPro Series or IsoPlane® SCT-320 spectrograph and for subsequent alignment and focusing of the spectrometer. Mounting the camera to an Acton SpectraPro Series spectrograph requires a male sliding tube that slides into the spectrograph for setting the alignment and focus. Mounting a camera to an IsoPlane is a matter of bolting it directly to the mounting plate on the IsoPlane. Once a camera has been mounted to the spectrograph, the camera must be aligned and focused to the spectrograph optics for the best signal acquisition.

NOTE:

When mounted to a spectrograph, the text on the back of the camera should be right side up.

F.1   Mount PI-MAX4 to an Acton SpectraPro Series Spectrograph

This section provides the procedure for mounting a PI-MAX4 with a 3.60 3-hole Slotted Flange to an Acton SpectraPro Series spectrograph.

F.1.1   Required Tools and Equipment

The following tools and equipment are required:

- 5/32" Hex wrench
- 5/16" Open end wrench[a]

- 3/32" Hex wrench
- (3) 10-32x ½" hex head stainless steel screws[a]

a.   Included in Spectrometer Kit bag

F.1.2   Procedure

Perform the following procedure to install a PI-MAX4 on an Acton SpectraPro Series Spectrograph

1.   Remove shipping plate and store.

2.   Remove spacer and store.
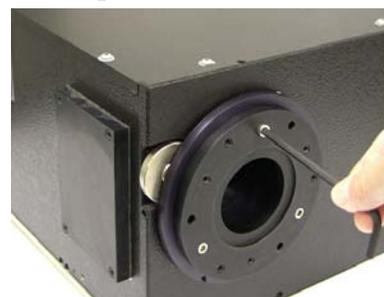
3. Loosen set screw with 3/32" hex wrench. **4.** Loosen set screw.
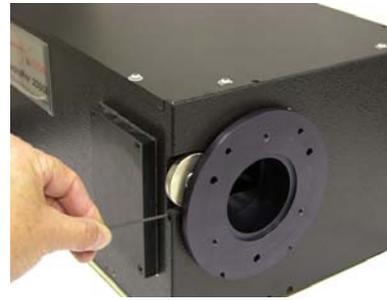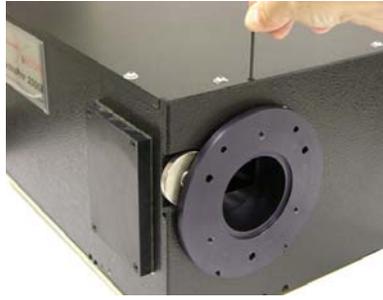
5. Gently rotate and pull.

6. Finger tighten hex head screws. Leave about ¼" thread exposed.

7. Mount tube to camera, align baffle with bottom/top of camera, and tighten mounting screws.

8. Gently rotate while inserting.

9. Tighten set screw.

10. Tighten set screw.

> 🔍 **NOTE:**
>
> Adapter parts are machined to provide a tight fit. It may be necessary to rotate the camera back and forth when inserting the sliding tube into the spectrograph. Forcing the tube into the spectrometer could permanently damage the tube and the spectrometer opening.

F.2   Mount a PI-MAX4 to an IsoPlane SCT-320 Spectrograph

This section provides the procedure for mounting a PI-MAX4 to an IsoPlane SCT-320 spectrograph.

F.2.1   Required Tools and Equipment

The following tools and equipment are required:

- 5/16" Open end wrench (provided in Spectrometer Kit bag)
- (3) 10-32 x ½" hex head stainless steel screws (from Shipping Plate removal or from Spectrometer Kit bag)

F.2.2   Procedure

Perform the following procedure to install a PI-MAX4 to an IsoPlane SCT-320 Spectrograph:

1. Remove shipping cover and store with washers. Hex head screws are used for mounting camera.

2. Finger tighten three hex head screws into the mounting plate. Leave about ¼" thread exposed.

3. Mount camera to mounting plate. Rotate camera until text on back is parallel to top of IsoPlane.

4. Using wrench, tighten down the three hex head screws.

> **NOTES:**
>
> 1. Rotational alignment of the camera to the spectrograph optics is done by loosening and subsequently re-tightening the screws at the mounting plate corners. The holes are slotted to allow about 4° of rotation.
>
> 2. If the IsoPlane was ordered with an internal shutter, an external shutter control box will be required to control the shutter or the shutter will need to be removed. See the IsoPlane SCT 320 manual for shutter removal instructions.

F.3 Spectrograph-Camera Rotational Alignment and Focusing

The camera mounting hardware provides two degrees of freedom: **rotation** and **focus**. In this context, rotation means physically rotating the camera while watching a live display and adjusting for optimum signal. Focus means to physically move the camera back and forth through the focal plane of the spectrograph while watching a live display to achieve the best signal. The following procedure, which describes the rotational alignment and focusing operations with an Acton SP-2300i spectrograph, can be easily adapted to other spectrographs.

> **REFERENCES:**
>
> For information about focusing and aligning an IsoPlane SCT-320 spectrograph, refer to Section F.3.2, Align and Focus an IsoPlane SCT-320 Spectrograph, on page 290.

> **NOTE:**
>
> When aligning other accessories, such as fibers, lenses, optical fiber adapters, first align the spectrometer to the slit. Then align the accessory without disturbing the camera position. The procedure is identical to that used to align and focus the camera to the spectrograph optics (i.e., do the alignment and focus operations while watching a live image.)

> **TIP:**
>
> 1. Use a USB-powered or a DC-powered light source. The 60 Hz of an AC-powered light source may make it more difficult to achieve focus.
>
> 2. If an AC light source must be used, set the SuperSYNCHRO Internal frequency to around 10 Hz.

F.3.1 Aligning and Focusing an Acton SpectraPro Series Spectrograph

Perform the following procedure to align and focus an Acton SpectraPro Series spectrograph:

1. Mount a light source such as a mercury pen-ray type in front of the entrance slit of the spectrograph. Any light source with line output can be used. **Standard fluorescent overhead lamps have good calibration lines as well.** If there are no line sources available, it is possible to use a broad band source such as tungsten for the alignment. If this is the case, use a wavelength setting of 0.0 nm for alignment purposes.

2. With the spectrograph properly connected to the computer, turn the power on, wait for the spectrograph to initialize.

3. With the camera mounted to the spectrograph and connected to the computer, turn on the power and wait for the camera to initialize.

4. Launch the application software.
   - When using WinSpec, a spectrograph must be defined.
   - When using LightField, the desired camera and spectrograph icons must be dragged into the **Experiment Devices** area.

5. Set the spectrograph to:
- 435.8 nm if using a mercury source, or
- 0.0 nm if using a broadband source.

> ☞ **TIP:** ─────────────────────────────────
>
> Overhead fluorescent lights produce a mercury spectrum. Use
> a white card tilted at 45° in front of the entrance slit to reflect
> overhead light into the spectrograph. Select 435.833 as the
> spectral line.

6. Set the slit to 10 µm at a minimum. If necessary, readjust the SuperSYNCHRO frequency to maintain optimum (near full-scale) signal intensity.

7. Make sure that the spectroscopy-mount adapter moves freely at the spectrograph. It may be necessary to loosen the two set screws that lock the sliding tube in place.

8. Begin running in **Focus** mode (WinSpec) or select **Align Spectrometer** from the **Experiment** menu in LightField. Adjust the setup as required.

After reviewing the list of changes, click on **Begin**.

9. Adjust the rotation by rotating the camera while watching a live display of the line. The line will go from broad to narrow and back to broad. Leave the camera rotation set for the narrowest achievable line.

Alternate Method:

Take an image of the slit, display the horizontal and vertical cursor bars, and compare the vertical bar to the line shape on the screen. Rotate the camera until the line shape on the screen is parallel with the vertical bar.

10. Once the camera has been aligned with the spectrograph optics, the focus must be optimized. Without disturbing the rotational alignment, move the camera in and out of focus. The spectral line go from broad to narrow and back to broad. Maximize the intensity level and minimize the FWHM of a selected peak or peaks.

In WinSpec, use the **Focus Helper** function (**Process —> Focus Helper…**) to determine the narrowest line width since it can automatically locate peaks and generate a report on peak characteristics during live data acquisition. Refer to the WinSpec/32 on-line help for more information.

Note that the way focusing is accomplished depends on the spectrograph, as follows:

- Long focal-length spectrographs such as the Acton SP-2300i
  The mounting adapter includes a tube that slides inside another tube to move the camera in or out as required to achieve optimum focus.

- Short focal-length spectrographs
  There is generally a focusing mechanism on the spectrograph itself which, when adjusted, will move the optics as required to achieve proper focus.

- No focusing adjustment
  If there is no focusing adjustment, either provided by the spectrograph or by the mounting hardware, then the only recourse will be to adjust the spectrograph's focusing mirror or to shim the camera.

11. Tighten the spectrograph set screws to secure the spectrograph adapter.

12. Halt data acquisition.

F.3.2   Align and Focus an IsoPlane SCT-320 Spectrograph

Because the PI-MAX4 or PI-MAX4-RF is mounted directly to the mounting plate on an IsoPlane, focusing and alignment is different from the way that rotational alignment and focusing are performed for an Acton SpectraPro Series spectrograph. The following information assumes that you are familiar with the locations of the mounting plate, Micrometer Compartment, and the locking set screw. If not, refer to the IsoPlane manual supplied with the spectrograph.

NOTES:

1. When adjusting focus for IsoPlane for the first time with a PI-MAX4 or PI-MAX4-RF, it is likely that the IsoPlane focus mirror will need to be adjusted. If the IsoPlane was previously used with a PIXIS or other Princeton Instruments camera with a back focus distance of approximately 0.6 inches, the focus setting will need to be changed to a much lower micrometer reading when focusing using a PI-MAX4 which has a back focus distance of approximately 0.9 inches.

2. If the camera has a 25 mm intensifier, some vignetting of the sides of the focal plane is normal. Vignetting is much less likely to occur if the camera has an 18 mm diameter intensifier.

3. If the IsoPlane was ordered with a shutter at the entrance slit and a PI-MAX4 or PI-MAX4F is to be used with this IsoPlane, the shutter must either be removed from the IsoPlane or controlled by an Acton SHC-EXT external shutter control box if one is available. Refer to the IsoPlane manual for shutter removal instructions.

Perform the following procedure to align and focus an IsoPlane SCT-320 spectrograph:

1. Mount a light source such as a Princeton Instruments Hg and Ne/Ar Dual Switchable light source in front of the entrance slit.

2. With the IsoPlane properly connected to the computer, turn the power on, wait for the spectrograph to initialize.

3. With the camera mounted to the spectrograph and connected to the computer, turn on the power and wait for the camera to initialize.

4. Launch the application software:
   - When using WinSpec, a spectrograph must be defined.
   - When using LightField, the desired camera and spectrograph icons must be dragged into the **Experiment Devices** area.

5. Set the spectrograph to:
   - 435.8 nm if using a mercury source, or
   - 0.0 nm if using a broadband source.

6. Set the slit to 10 μm at a minimum. If necessary, readjust the SuperSYNCHRO frequency to maintain optimum (near full-scale) signal intensity.

7. Wait until the camera locks at its default temperature.

8. Turn on **Focus** mode (WinX) or select **Align Spectrometer** from the **Experiment** menu (LightField.) If you are using LightField, review the changes the software will make before clicking on **Begin**.

9. Using a 9/64" hex wrench, loosen the four screws at the corners of the camera mounting plate.

10. While continuously acquiring data, click on the peak being monitoring for the alignment. This will display the data cursor which can be positioned at the top of the peak. When using LightField, the data cursor spans the ROIs (graphs) and the data cursor can be used as the vertical reference.

> **NOTE:**
>
> In WinSpec, you can set up three ROIs (one at the top, middle, and bottom of the array) with 10 rows binned for each via the **Experiment Setup —> ROIs** tab. Then change the data display via the **Display Layout** dialog so that **3d Graph** is selected (**General** tab,) the **Z Axis Endpoints** (**3D Layout** tab) are %X = 0 and %Y = 40, and the **Save as Default** check box is checked. After clicking on **OK**, you should see three stacked graphs.

11. Slowly rotate the camera until you achieve narrowest achievable peak or if you have stacked ROIs, the selected peak aligns horizontally in all of the ROIs.

12. After completing the rotational alignment, tighten the four mounting plate screws.

13. Using a 9/64" hex wrench, remove the cover from the Micrometer Compartment.

14. Using a 3/32" hex wrench, loosen the micrometer locking set screw.

15. Since you are still continuously acquiring data, adjust the micrometer until you maximize the intensity level and minimize the FWHM of a selected peak or peaks. Note that in LightField the **Peak Find** function (for the graph selected by the cursor) is automatically turned on to help you identify peaks and view FWHM widths.

16. Tighten down the locking set screw.

17. Place the Micrometer Cover on the spectrograph. Replace and tighten all of the cover screws.

18. Stop continuous data acquisition.

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Appendix G: Accessories

G.1   Accessory Kits

The camera is shipped with the adapter mount specified when it was purchased. If a kit for an additional adapter mount is also purchased, it will be shipped in an accessory kit containing a double-ended screwdriver with magnet top. When the additional adapter is a spectroscopy mount adapter, a quick start guide will be provided which describes how to mount the camera to Acton SpectraPro Series spectrograph. A similar quick start is shipped when an IsoPlane spectrograph is ordered.

> 📋 **NOTE:**
>
> The quick start information for each type of spectrograph is included in Appendix F, Spectrograph Mount Information.

G.2   Adapter Kits

Refer to Table G-1 for information about available adapter kits that may be included in the accessory kit.

Table G-1:   Adapter Kit Information

Kit	Part Number	Description/Contents
C-Mount Adapter	2530-0074	Adapter, 4-40x 7/16 flat head Phillips screws, dust cover
F-Mount Adapter	2530-0076	Adapter, 4-40x 7/16 flat head Phillips screws, dust cover
Spectroscopy-Mount Adapter	2530-0075	Adapter, 4-40x7/16 flat head Phillips screws, dust cover
IVUV/NVUV Spectroscopy-Mount Adapter	2530-0082	Adapter, 4-40x7/16 flat head Phillips screws, o-ring (2.739" I.D.,) o-ring (2.614" I.D.,) dust cover

Figure G-1 illustrates the reversible screwdriver that is included with the accessory kit.

Figure G-1:   Magnetic Screwdriver with Reversible Flat and Phillips Bit

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G.3 Quick Start Guide

When a camera system is shipped with a spectroscopy-mount adapter kit, a quick start guide for mounting a PI-MAX4 with spectroscopy-mount adapter to an Acton spectrograph is included. Typically, the guide assumes that there is a spectroscopy-mount adapter pre-mounted to the PI-MAX4 camera.

G.4 Standard C-, F-, and Spectroscopy-Mount Adapters

Figure G-2 shows three different mounts that are available for use on a PI-MAX4 camera.

Figure G-2: Standard PI-MAX4 Mount Adapters
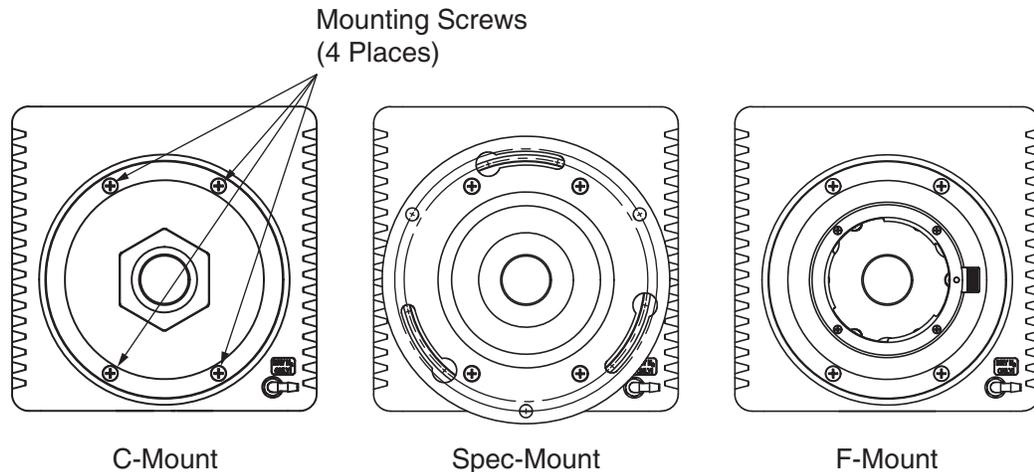
4411-0137_0175

Perform the following procedure to replace one adapter with another:

1. Use the supplied screwdriver to remove the four (4) Phillips head screws that secure the current adapter to the front of the PI-MAX4.

   > **NOTE:**
   >
   > If the Phillips end of the screwdriver is not available, pull the driver shaft out of the handle, flip the shaft, and insert the flat end into the handle.

2. Remove the existing adapter and store it in a safe place.

3. Using the four (4) screws removed in step 1, mount the new adapter to the front of the PI-MAX4.

G.5 Spectroscopy-Mount for IVUV and NVUV Cameras

In addition to the spectroscopy adapter, IVUV/NVUV cameras require two o-rings to be installed:

- A 2.739" inner diameter o-ring is installed between the face the camera and the spectrograph's adapter;
- A 2.614" inner diameter o-ring is installed into a groove on the face of the spectrograph's adapter.

NOTE:

Prior to installing each o-ring, a thin coat of vacuum grease must be applied to guarantee an adequate seal is achieved.

Figure G-3 illustrates where these o-rings are located.

Figure G-3: Standard, IVUV, and NVUV Spectroscopy Mounts

Standard Configuration   IVUV (Vacuum) Configuration   NVUV (Nitrogen Back-filled) Configuration
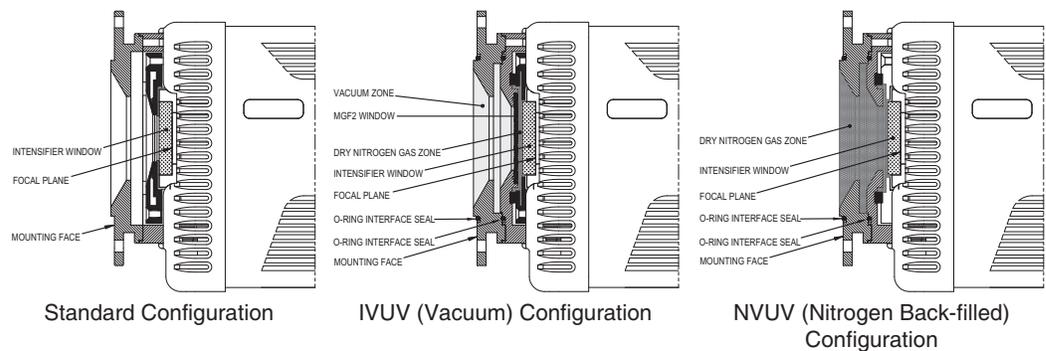
4411-0137_0176

Typically, cameras are shipped with the adapter already mounted to the face of the camera and the o-rings already in place.

G.5.1 Installation Procedure

Perform the following procedure to install an IVUV/NVUV spectroscopy mount onto a PI-MAX4 camera:

1. Use the supplied screwdriver to remove the four (4) Phillips head screws that secure the current adapter to the front of the PI-MAX4.

NOTE:

If the Phillips end of the screwdriver is not available, pull the driver shaft out of the handle, flip the shaft, and insert the flat end into the handle.

2. Remove the existing adapter and store it in a safe place.

3. Apply a thin layer of vacuum grease to each of the o-rings.

4. Position the 2.739" inner-diameter o-ring into the groove on the face of the camera. See Figure G-4.

Figure G-4:   Positioning the 2.739" (ID) O-ring

2.739" (ID) O-ring In Groove

4411-0137_0177

5. Using the four (4) screws removed in step 1, mount the spectroscopy-mount adapter to the front of the PI-MAX4.

6. Position the smaller diameter o-ring into the groove on the face of the adapter. See Figure G-5.

Figure G-5:   Positioning the 2.614" (ID) O-ring

2.614" (ID) O-ring In Groove

4411-0137_0178

NOTE:

A spare set of o-rings may be provided. When installing a new o-ring, be sure to apply a thin coat of vacuum grease before putting it in place. Lightly coating the o-rings with vacuum grease helps to insure an air-tight seal is formed between the camera and adapter, and between the adapter and the spectrograph sliding tube.

G.6 Optical Distance from Mounting Face to Image Plane

Each adapter has a preset optical distance from the mounting face to the image plane. The distance varies from one adapter type to another and is described in greater detail on the PI-MAX4 outline drawings.

For quick reference, the distances are provided here:

- **C-Mount**
  Mounting face to image plane is factory preset to an optical distance of 0.690" ± 0.010" [17.53 mm ± 0.25 mm].

- **Spectroscopy**
  Mounting face to image plane is factory preset to an optical distance of 0.894" ± 0.010" [22.71 mm ± 0.25 mm].

- **F-Mount**
  Mounting face to image plane is factory preset to an optical distance of 1.831" ± 0.010" [46.50 mm ± 0.25 mm].

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Appendix H: Glossary

Binning

A process that may occur in the readout register and the output node (on-chip or hardware binning) or is performed as a post-process (software binning.) Binning combines charge from rectangular groups of adjacent pixels into super pixels. When done on-chip, this process reduces readout time and the burden on computer memory; the drawbacks are lowered resolution and the possibility of saturation and blooming. Software binning avoids the problem of saturation and blooming.

Blooming

The spillover of excess charge into adjacent pixels.

Bracket Pulsing

Refer to MCP Bracket Pulsing.

CCD Array Dimensions and Pixel Size

Arrays that are square or nearly square are typically used for imaging applications, while rectangular arrays are typically used in spectroscopy applications. The smaller the pixel size, the better the resolution, but the pixel full-well capacity smaller. Conversely, the larger the pixel size, the poorer the resolution, and the greater the pixel full-well capacity.

CCD Array Dynamic Range

The dynamic range of a CCD is the maximum achievable signal divided by the camera noise, where the signal strength is determined by the full-well capacity and noise is the sum of dark and read noises. The greater the dynamic range, the better the CCD is able to detect differences between the dimmest and brightest intensities in an image. The readout speed affects the dynamic range of a pixel: the faster the speed, the higher the noise, and the smaller the dynamic range.

CCD Spectral Sensitivity

Coatings applied to the CCD input window can enhance sensitivity in the UV regions. Deep-depletion enhances sensitivity in the NIR.

Dark Charge or Dark Current

The thermally induced buildup of charge in the CCD over time. Dark charge values vary widely from one CCD array to another and are exponentially temperature dependent. In the case of cameras that have MPP type arrays, the average dark charge is extremely small. However, the dark-charge distribution is such that a significant number of pixels may exhibit a much higher dark charge, limiting the maximum practical exposure. To minimize the collection of dark charge, operate the camera at the lowest CCD temperature possible.

Since each CCD has its own dark charge pattern, unique to that particular device, acquiring and saving a dark charge "background image" under conditions identical to those used to acquire the "actual" image and then subtracting that image from the actual image will significantly reduce dark-charge effects.

EBI

Equivalent Background Illumination. EBI comes from thermally-generated electrons that cannot be distinguished from those generated by light photons. EBI can be reduced by cooling the intensifier (or environment) and is usually negligible in gated applications.

Exposure Time

The period during which the camera allows incoming signal to integrate on the CCD array. For signal to be detected and integrated on the CCD array, it must both fall in a valid gate width and in a valid exposure time. In **Gate Mode**, the exposure time is determined by an internal pulse ensemble defined by the internal timing generator gating setup.

External Sync

Readout synchronization mode where the CCD array is synchronized to an external source, i.e., the array is scanned upon arrival of an external trigger pulse.

External Trigger Mode

Trigger mode where gate pulses are delayed from external input trigger pulses. Also a camera readout synchronization mode where the camera is scanned continuously but data storage does not begin until the arrival of an external trigger pulse.

Frame

The area of the CCD array that is readout after an exposure time ends. For a 1024x1024 array, a full frame would consist of the entire 1024x1024 pixel area. In the WinX/32 software, the number of frames to be acquired during a data acquisition is determined by the Number of Images (or Number of Spectra) parameter on the **Experiment Setup —> Main** tab. If the parameter value is greater than 1, multiple frames of data will be acquired and stored in a single data file.

Frame Rate (fps)

The number of frames that can be readout per second. The effective frame rate can be increased by defining a Region of Interest (ROI) that is smaller than the full-frame size. This means that a selected portion of the image can be displayed and the remainder of the accumulated charge discarded. The frame rate generally increases with reduction in the size of the detected area. For example, a CCD with a sensor size of 1000 x 1000 and an output rate of ten frames/second can produce 100 frames/second if the read-out region is reduced to 100 x 100 pixels.

Full-Well Capacity

The number of electrons that can be stored in a pixel. The smaller the pixel, the fewer electrons can be stored; therefore, either the exposure times need to be shorter or the signal intensity must be lower. Note that binning relies on the full-well capacity of the pixels in the serial shift register and of the output node. Typically, a serial shift register pixel has a full-well capacity that is 2 times greater than that of an image pixel and the output node has a full-well capacity that is about 1.5-2 times greater than that of a serial register pixel.

FWHM

Full width half-maximum. Time period from the mid-point of the leading edge to the mid-point of the trailing edge of the gate pulse. Used to describe pulse width.

Gate Delay

The time between the beginning of the trigger pulse (either internal or external) and the beginning of the photocathode gate pulse.

Gate Mode

PI-MAX4 intensifier mode in which the photocathode is biased on only for the time that each gate pulse is applied. In this way, the array can be exposed to multiple images during a single exposure time. As a result, the tolerance to room light is higher in gated operation, but the risk of damaging overload from intense light sources such as lasers remains. In fact, intense light sources in gated experiments can cause spot damage that would be undetected by the alarm circuit.

Gate Width

The time during which light will be detected by the intensifier, intensified, and applied to the CCD. Basically, the intensifier controls what the chip 'sees' during the exposure time. For signal to be detected, it must both fall in a valid gate width and in a valid exposure time.

Input Windows

The intensifier and the CCD array both have input windows.

- MgF_2

    High vacuum UV transmission (between 100 nm and 200 nm.)

- Quartz

    Excellent transmission over 190 nm - 1100 nm.

- Clear glass (BK7)

    Visible (400 nm -700 nm) and NIR (700 nm - 2500 nm.)

Anti-Reflection (A/R) coatings may be added to input windows to reduce signal loss and glare caused by reflection.

Intensifier-CCD Coupling

Transmission of the emitted photons is either through a fiber-optic bundle or with a lens. The drawback to lens coupling is lower throughput (5%-10%) and increased stray light in the camera system. The advantages are that the intensifier can be removed and the camera can be used as a standard CCD imager conversely an intensifier can be added to an existing camera.

Fiber-optic coupling results in a throughput of > 60%, are capable of sensitivities approaching single-photoelectron detection, and have a much better signal-to-noise ratio (SNR) than lens-coupled devices. Disadvantages are that the fiber-optic bundle is permanently attached to the CCD array and that the camera must be operated in a dry, non-vacuum inert environment.

Intensifier Gating Speed

Temporal resolution in a PI-MAX4 is made possible by switching the intensifier on and off (gating) very rapidly. Typical fast-gate intensifiers have minimum gate widths (FWHM=full width at half-maximum gate pulse) of approximately 2 ns. For slow-gated devices the FWHM is about 50 ns.

Fast-gating is achieved by adding a nickel (Ni) under layer to the photocathode. However, this layer may produce an effective QE reduction of as much as 40%. Slow-gate intensifiers have neither the Ni layer nor its effects on QE.

Intensifier On/Off Ratio

The ratio of light output when the intensifier is gated on and off: The higher the ratio, the better the gating. A high on/off ratio is necessary to eliminate the background and to faithfully reproduce transient events. In the visible region on/off ratios exceeding 10^6:1 is typically achieved. In the UV region, the on/off ratio is typically much poorer (10^4:1) though with MCP Bracket Pulsing, ratios in the UV region can be improved dramatically (10^7:1.) Refer to Section 7.4, Micro-Channel Plate (MCP) Bracket Pulsing, on page 122, for additional information.

Intensifier Size

18 mm diameter and 25 mm diameter. Generally speaking, the larger diameter gives a larger field of view at the surface of the CCD array. The coupling of the intensifier to the CCD array is also a factor in determining the field view. A fiber-optic reducing taper of 1.27:1 will increase the field of view, while a taper of 1:1 will have no effect.

Intensifier Types

Gen I [Obsolete]

Developed in the early 1960s. Used electrostatic focusing and electron acceleration to achieve signal gains up to 150. These intensifiers could detect images under ambient light intensity as low as 0.01 lux. Problems included image distortion, short-lived components, and large size.

GenII

Introduced in the late 1960s and early 1970s. Incorporated MCPs with resulting signal gain improvement (up to 20,000.) Not as efficient as Gen I intensifiers, however have high resolution, no image distortion, and are small. Can detect images under ambient light intensity as low as 0.001 lux.

Super Gen II

Gen II devices that employ novel photocathodes with extended spectral range or high QE in a particular wavelength.

Gen III

Gen II technology with GaAs added as the photocathode coating. Highly sensitive in the NIR region above 800 nm but relatively insensitive in the blue/green region. Utilizes high-resolution MCPs (6 µm diameter channels) and ion-barrier films. Two to three orders of magnitude more sensitive to light than Gen II devices. Can detect images under ambient light intensify as low as 0.0001 lux.

Filmless Gen III

Filmless Gen III devices use GaAsP photocathodes which have no ion barrier film (MCP.) The Gen III filmless intensifiers offer ultra-fast gating as well as >50% QE for the best combination of sensitivity in the visible region (<780 nm) and gate speed.

Gen IV

Introduced in 1999. No ion barrier film and exhibit enhanced QE, SNR, dynamic range, and high-light-level resolution.

lp/mm

Line Pairs per Millimeter. A measure of resolution based on the ability of the imaging system to differentiate between two parallel lines. The higher the value, the finer the resolution.

MCP

Micro-Channel Plate. Composed of cylindrical channels through which electrons from the photocathode travel and generate additional electrons resulting in electron gain. At the output of the MCP is a phosphor-coated fluorescent screen that converts the electrons to photons that subsequently strike the CCD array and generate charge in the array pixels.

MCP Bracket Pulsing

Available for PI-MAX4 cameras with Gen II intensifiers. This technique enhances the intensifier's on/off ratio in UV measurements by automatically adjusting the on/off switching of the MCP to bracket the photocathode gate pulse. By switching off the MCP, unwanted UV signal that strikes the photocathode (even though gated off) is prevented from passing through the MCP to integrate on the CCD array.

MCP Gating

Available for PI-MAX$_{MG}$ cameras. Applies the primary gating pulse to the MCP portion of the tube and, if chosen by the user, applies the bracket pulse to the photocathode.

MCP Resolution

The MCP is a slightly conductive glass substrate with millions of parallel traversing channels containing a secondary electron emitter on their inner walls. The smaller the diameter and more tightly grouped the channels, the higher the resolution.

Phosphor Decay Time

A delay between the end of the exposure time and the beginning of the array readout. This time is inserted to allow the phosphor to decay to 1% before readout occurs and will vary depending on the phosphor type.

Phosphor Type

A phosphor is a chemical substance that fluoresces when excited by x-rays, an electron beam, or ultraviolet radiation. Phosphors usually emit green light with decay times ranging from hundreds of nanoseconds to a few milliseconds. P43 offers high resolution (~ 3 ms decay) while P46 offers fast decay for high-repetition rate spectroscopy (~ 2 µs decay.) The P47 offers even faster decay (0.4 µs.) The Phosphor Decay Time, inserted between the end of the exposure time and the beginning of the array readout, allows for the decay time.

Photocathode Coatings

Coatings on the photocathode convert a portion of the incident photons into electrons. Any photons that are not captured by the photocathode are lost from the final signal produced by the intensifier. Therefore, the kind of coating and the resulting QE of the photocathode is very important. The choice of coating determines the most effective spectral range for the intensifier. For example GaAs (gallium arsenide) has high QE in the VIS and NIR regions. Multi-alkali coatings have fair photoconversion in the visible (VIS) and ultraviolet (UV) but have relatively limited response in the near IR (NIR.)

Pulse Ensemble

Consists of a Gate Start pulse, a Gate Stop pulse, and an Auxiliary pulse. At the end of the ensemble, the photocathode is gated off, phosphor decay time elapses to allow for phosphor decay, and then the CCD array is readout.

QE

Quantum Efficiency. The percentage of incident photons converted to electronic charge. The throughput of the input windows, the spectral sensitivity of the photocathode and the CCD array, the illuminated surface (front or back) of the CCD array, the intensifier on/off ratio, the MCP resolution, the MCP gain, and the intensifier-CCD coupling all contribute to the total system QE.

RAM

Random Access Memory used to store data such as experiment parameters.

Region of Interest (ROI)

A square or rectangular set of contiguous pixels on the CCD array that is usually smaller than the full frame. Using an ROI to acquire data results in a faster readout of the array since data from pixels outside of that ROI is discarded.

Safe Mode

PI-MAX4 intensifier mode in which the photocathode is continuously biased off.

Saturation

Caused when a pixel well is completely filled with charge. Once a pixel is saturated, additional charge will spillover (bloom) into adjacent pixels. Ways to deal with saturation include lowering the array temperature (to reduce the dark charge component,) shortening the exposure time (to reduce the signal component,) and decreasing the gain (also to reduce the signal component.)

Scan or Scanning

The process of reading out the contents of a CCD array.

Vertical Shift Time (μs)

The time, in microseconds, required to vertically shift a single row. This information is based on the value in the Vertical Shift box. The larger the Vertical Shift value, the longer the Vertical Shift Time. This information appears for the Frame Transfer.

> **NOTE:**
>
> PI-MAX4: EM cameras have an inherent 2.4 μs overhead delay that must be included when calculating the Vertical Shift time. This overhead is a constant value regardless of the number of rows being transferred.
>
> The total time required to transfer an image may be calculated using the following formula:
>
> $$[(\# \text{ of rows}) \times (t_{VS})] + 2.4 \text{ μs}$$

Vertical Shift

Determines the speed of the image transfer from the exposed area of an array to the masked area. Setting a lower value increases the shift speed. A higher value gives a slower shift. If the shift is too fast, not all of the charge will be transferred. If too slow, image smearing will be increased due to the exposure that takes place while the transfer is in progress. The default value gives good results in most measurements.

Declaration of Conformity

This section of the PI-MAX4 system manual contains the declarations of conformity for PI-MAX4 and PI-MAX4: 1024i-RF systems. A system includes the camera with a Gen II or Filmless Gen III intensifier and its power supply.

DECLARATION OF CONFORMITY

We, the undersigned

    Manufacturer: Roper Scientific (Princeton Instruments)
    Address, City: 3660 Quakerbridge Road, Trenton, NJ 08619
    Country: USA

    Authorized Representative in Europe: Roper Scientific, GmbH
    Address, City: Rosenheimer Landstr. 87, D-85521, Ottobrunn
    Country: Germany

Certify and declare under our sole responsibility that the following apparatus:

    PI-MAX4 Camera with Power Supply,

    Model ID Prefix: PM4

Conforms to the emissions requirements of EN61326-1:2006; Clause 7.2:

CISPR 11 Edition 4: 2003	**Conducted Emissions, Group 1, Class A**
CISPR 11 Edition 4: 2003	**Radiated Emissions, Group 1, Class A**
IEC 61000-3-2: 2000	**Harmonics**
IEC 61000-3-3: 2002	**Flicker**

Conforms to the immunity requirements of EN61326-1:2006; Table 1:

IEC 61000-4-2: 2001	**Electrostatic Discharge**
IEC 61000-4-3: 2002	**Radiated Immunity**
IEC 61000-4-4: 2004	**EFT/Burst, Power Leads, and I/O Cables**
IEC 61000-4-5: 2001	**Surge Immunity, Power Leads**
IEC 61000-4-6: 2003	**Conducted Immunity, Power Leads, and I/O Cables**
IEC 61000-4-11: 2004	**Voltage Dips and Interrupts**

And follows the provisions of Low Voltage Directive and Safety:

    CE Low Voltage Directive 2006/95/EC
    EMC Directive 2004/108/EC
    Product Safety Regulations and Standards IEC 61010-1: 2010

The technical documentation is kept at the following address:

Company:	**Princeton Instruments**
Address, City, State:	**3600 Quakerbridge Rd, Trenton, NJ 08619**
Country:	**USA**
Telephone Number:	**+1 800.874.9789/+1 609.587.9797**
Fax Number:	**+1 609.587.1970**

Name and Position of Person Binding the Manufacturer or his Authorized Representative:

William Asher   **Signature:** *William C. Asher*

President   **Date:** *June 19, 2013*

DECLARATION OF CONFORMITY

We, the undersigned

Manufacturer: Roper Scientific (Princeton Instruments)
Address, City: 3660 Quakerbridge Road, Trenton, NJ 08619
Country: USA

Authorized Representative in Europe: Roper Scientific, GmbH
Address, City: Rosenheimer Landstr. 87, D-85521, Ottobrunn
Country: Germany

Certify and declare under our sole responsibility that the following apparatus:

PI-MAX4-RF Camera with Power Supply,

Model ID Prefix: PM4

Conforms to the emissions requirements of EN61326-1:2006; Clause 7.2:

CISPR 11 Edition 4: 2003	**Conducted Emissions, Group 1, Class A**
CISPR 11 Edition 4: 2003	**Radiated Emissions, Group 1, Class A**
IEC 61000-3-2: 2000	**Harmonics**
IEC 61000-3-3: 2002	**Flicker**

Conforms to the immunity requirements of EN61326-1:2006; Table 1:

IEC 61000-4-2: 2001	**Electrostatic Discharge**
IEC 61000-4-3: 2002	**Radiated Immunity**
IEC 61000-4-4: 2004	**EFT/Burst, Power Leads, and I/O Cables**
IEC 61000-4-5: 2001	**Surge Immunity, Power Leads**
IEC 61000-4-6: 2003	**Conducted Immunity, Power Leads, and I/O Cables**
IEC 61000-4-11: 2004	**Voltage Dips and Interrupts**

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CE Low Voltage Directive 2006/95/EC
EMC Directive 2004/108/EC
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Telephone Number:	**+1 800.874.9789/+1 609.587.9797**
Fax Number:	**+1 609.587.1970**

Name and Position of Person Binding the Manufacturer or his Authorized Representative:

William Asher

President

Signature: _William E. Asher_
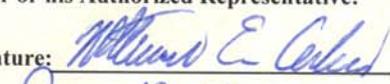
Date: _June 19, 2013_

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Warranty & Service

Limited Warranty

Princeton Instruments, a division of Roper Scientific, Inc. ("Princeton Instruments", "us", "we", "our") makes the following limited warranties. These limited warranties extend to the original purchaser ("You", "you") only and no other purchaser or transferee. We have complete control over all warranties and may alter or terminate any or all warranties at any time we deem necessary.

Basic Limited One (1) Year Warranty

Princeton Instruments warrants this product against substantial defects in materials and / or workmanship for a period of up to one (1) year after shipment. During this period, Princeton Instruments will repair the product or, at its sole option, repair or replace any defective part without charge to you. You must deliver the entire product to the Princeton Instruments factory or, at our option, to a factory-authorized service center. You are responsible for the shipping costs to return the product. International customers should contact their local Princeton Instruments authorized representative/distributor for repair information and assistance, or visit our technical support page at www.princetoninstruments.com.

Limited One (1) Year Warranty on Refurbished or Discontinued Products

Princeton Instruments warrants, with the exception of the CCD imaging device (which carries NO WARRANTIES EXPRESS OR IMPLIED,) this product against defects in materials or workmanship for a period of up to one (1) year after shipment. During this period, Princeton Instruments will repair or replace, at its sole option, any defective parts, without charge to you. You must deliver the entire product to the Princeton Instruments factory or, at our option, a factory-authorized service center. You are responsible for the shipping costs to return the product to Princeton Instruments. International customers should contact their local Princeton Instruments representative/distributor for repair information and assistance or visit our technical support page at www.princetoninstruments.com.

XP Vacuum Chamber Limited Lifetime Warranty

Princeton Instruments warrants that the cooling performance of the system will meet our specifications over the lifetime of an XP style detector (has all metal seals) or Princeton Instruments will, at its sole option, repair or replace any vacuum chamber components necessary to restore the cooling performance back to the original specifications at no cost to the original purchaser. *Any failure to "cool to spec" beyond our Basic (1) year limited warranty from date of shipment, due to a non-vacuum-related component failure (e.g., any components that are electrical/electronic) is NOT covered and carries NO WARRANTIES EXPRESSED OR IMPLIED.* Responsibility for shipping charges is as described above under our Basic Limited One (1) Year Warranty.

Sealed Chamber Integrity Limited 12 Month Warranty

Princeton Instruments warrants the sealed chamber integrity of all our products for a period of twelve (12) months after shipment. If, at anytime within twelve (12) months from the date of delivery, the detector should experience a sealed chamber failure, all parts and labor needed to restore the chamber seal will be covered by us. *Open chamber products carry NO WARRANTY TO THE CCD IMAGING DEVICE, EXPRESSED OR IMPLIED.* Responsibility for shipping charges is as described above under our Basic Limited One (1) Year Warranty.

Vacuum Integrity Limited 12 Month Warranty

Princeton Instruments warrants the vacuum integrity of "Non-XP" style detectors (do not have all metal seals) for a period of up to twelve (12) months from the date of shipment. We warrant that the detector head will maintain the factory-set operating temperature without the requirement for customer pumping. Should the detector experience a Vacuum Integrity failure at anytime within twelve (12) months from the date of delivery all parts and labor needed to restore the vacuum integrity will be covered by us. Responsibility for shipping charges is as described above under our Basic Limited One (1) Year Warranty.

Image Intensifier Detector Limited One Year Warranty

All image intensifier products are inherently susceptible to Phosphor and/or Photocathode burn (physical damage) when exposed to high intensity light. Princeton Instruments warrants, with the exception of image intensifier products that are found to have Phosphor and/or Photocathode burn damage (which carry NO WARRANTIES EXPRESSED OR IMPLIED,) all image intensifier products for a period of one (1) year after shipment. *See additional Limited One (1) year Warranty terms and conditions above, which apply to this warranty.* Responsibility for shipping charges is as described above under our Basic Limited One (1) Year Warranty.

X-Ray Detector Limited One Year Warranty

Princeton Instruments warrants, with the exception of CCD imaging device and fiber optic assembly damage due to X-rays (which carry NO WARRANTIES EXPRESSED OR IMPLIED,) all X-ray products for one (1) year after shipment. Se*e additional Basic Limited One (1) year Warranty terms and conditions above, which apply to this warranty.* Responsibility for shipping charges is as described above under our Basic Limited One (1) Year Warranty.

Software Limited Warranty

Princeton Instruments warrants all of our manufactured software discs to be free from substantial defects in materials and / or workmanship under normal use for a period of one (1) year from shipment. Princeton Instruments does not warrant that the function of the software will meet your requirements or that operation will be uninterrupted or error free. You assume responsibility for selecting the software to achieve your intended results and for the use and results obtained from the software. In addition, during the one (1) year limited warranty. The original purchaser is entitled to receive free version upgrades. Version upgrades supplied free of charge will be in the form of a download from the Internet. Those customers who do not have access to the Internet may obtain the version upgrades on a CDROM from our factory for an incidental shipping and handling charge. *See Item 12 in the following section of this warranty ("Your Responsibility") for more information.*

Owner's Manual and Troubleshooting

You should read the owner's manual thoroughly before operating this product. In the unlikely event that you should encounter difficulty operating this product, the owner's manual should be consulted before contacting the Princeton Instruments technical support staff or authorized service representative for assistance. If you have consulted the owner's manual and the problem still persists, please contact the Princeton Instruments technical support staff or our authorized service representative. *See Item 12 in the following section of this warranty ("Your Responsibility") for more information.*

Your Responsibility

The above Limited Warranties are subject to the following terms and conditions:

1. You must retain your bill of sale (invoice) and present it upon request for service and repairs or provide other proof of purchase satisfactory to Princeton Instruments.

2. You must notify the Princeton Instruments factory service center within (30) days after you have taken delivery of a product or part that you believe to be defective. With the exception of customers who claim a "technical issue" with the operation of the product or part, all invoices must be paid in full in accordance with the terms of sale. Failure to pay invoices when due may result in the interruption and/or cancellation of your one (1) year limited warranty and/or any other warranty, expressed or implied.

3. All warranty service must be made by the Princeton Instruments factory or, at our option, an authorized service center.

4. Before products or parts can be returned for service you must contact the Princeton Instruments factory and receive a return authorization number (RMA.) Products or parts returned for service without a return authorization evidenced by an RMA will be sent back freight collect.

5. These warranties are effective only if purchased from the Princeton Instruments factory or one of our authorized manufacturer's representatives or distributors.

6. Unless specified in the original purchase agreement, Princeton Instruments is not responsible for installation, setup, or disassembly at the customer's location.

7. Warranties extend only to defects in materials or workmanship as limited above and do not extend to any product or part which:

   • has been lost or discarded by you;
   • has been damaged as a result of misuse, improper installation, faulty or inadequate maintenance or failure to follow instructions furnished by us;
   • has had serial numbers removed, altered, defaced, or rendered illegible;
   • has been subjected to improper or unauthorized repair;
   • has been damaged due to fire, flood, radiation, or other "acts of God" or other contingencies beyond the control of Princeton Instruments; or
   • is a shutter which is a normal wear item and as such carries a onetime only replacement due to a failure within the original 1 year Manufacturer warranty.

8. After the warranty period has expired, you may contact the Princeton Instruments factory or a Princeton Instruments-authorized representative for repair information and/or extended warranty plans.

9. Physically damaged units or units that have been modified are not acceptable for repair in or out of warranty and will be returned as received.

10. All warranties implied by state law or non-U.S. laws, including the implied warranties of merchantability and fitness for a particular purpose, are expressly limited to the duration of the limited warranties set forth above. With the exception of any warranties implied by state law or non-U.S. laws, as hereby limited, the forgoing warranty is exclusive and in lieu of all other warranties, guarantees, agreements, and similar obligations of manufacturer or seller with respect to the repair or replacement of any parts. In no event shall Princeton Instruments' liability exceed the cost of the repair or replacement of the defective product or part.

11. This limited warranty gives you specific legal rights and you may also have other rights that may vary from state to state and from country to country. Some states and countries do not allow limitations on how long an implied warranty lasts, when an action may be brought, or the exclusion or limitation of incidental or consequential damages, so the above provisions may not apply to you.

12. When contacting us for technical support or service assistance, please refer to the Princeton Instruments factory of purchase, contact your authorized Princeton Instruments representative or reseller, or visit our technical support page at www.princetoninstruments.com.

Contact Information

Roper Scientific's manufacturing facility for this product is located at the following address:

Princeton Instruments
3660 Quakerbridge Road
Trenton, NJ 08619 (USA)

Tel: 1-800-874-9789 / 1-609-587-9797
Fax: 1-609-587-1970

Customer Support E-mail: techsupport@princetoninstruments.com

For immediate support in your area, please call the following locations directly:

North America	800 899 1144 (toll free) or 609 587 9797
France	+33 (1) 60 86 03 65
Germany	+49 (0) 89 660 7793
Japan	+81 (3) 5639 2741
UK & Ireland	+44 (0) 1628 472 346
Singapore	+65 6408 6240
China	+86 10 659 16460

Otherwise, refer to our Support web page at www.princetoninstruments.com.

An up-to-date list of addresses and telephone numbers is posted on the www.princetoninstruments.com/Support page. In addition, links on this page to support topics allow you to send e-mail based requests to the Customer Support group.

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